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Change of Electrical resistance

in a magnetic field

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CHANGE OF ELECTRICAL RESISTANCE IN A MAGNETIC FIELD.

WITH EXPERIMENTS ON THE CHANGE OF RESISTANCE OF ELECTROLYTES

BY

WILLIAM WARREN STIFLER
A.B., SHURTLEFF COLLEGE, 1902

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS

IN

PHYSICS

IN THE

GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

JUNE, 1908

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WILLIAM WARREN STIFLER

ENTITLED CHANGE OF ELECTRICAL RESISTANCE IN A MAGNETIC FIELD WITH EXPERIMENTS ON THE CHANGE OF RESISTANCE OF ELECTROLYTES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Master of Arts in Physics

A. P. Carman

Instructor in Charge.

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Introduction.

Since 1857 when Sir William Thomson first observed that magnetization altered the electrical resistance of iron and nickel, the effect of magnetic fields upon electrical conductivity has been the subject of careful experimental and theoretical investigation. Tomlinson, Lenard, and Goldhammer were among the earlier experimental investigators. More recent work has been done by Patterson and Grunmach. The theoretical bearings of the results have been discussed by J. J. Thomson and E. P. Adams.

The purpose of this paper is to give:-

I. An account of the work which has been done on the alteration of the resistance of metals when placed in a magnetic field, with a critical estimate of the work of each investigator.

II. A discussion of the explanation of these results on the electron theory.

III. An account of the work done by others upon the effects of magnetic fields upon electrolytic resistances, with a more detailed account of the experiments carried on by the author and a discussion of the results obtained by him.

Metallic Conductors in a Magnetic Field.

Under the general title "The Electrodynamic Qualities of Metals" (Math. & Phys. Papers, Vol.II, pp. 307-331.) Lord Kelvin gives an account of the first observations on this effect. His initial experiments were on the effects produced in iron and steel wires by longitudinal magnetization. His method throughout was essentially that of the Wheatstone's Bridge. One arm consisted of the test sample which was provided with a suitable magnetizing coil. The other arm was a similar sample without the magnetizing coil. Both samples were water-jacketed to insure constant temperature. An iron wire showed an increase of about 1 part in 3000 when in the field. A steel wire gave similar results, and also showed a permanent increase of resistance due to residual magnetization.

The first experiments on the effect of transverse magnetization were made with a strip of thin sheet iron 7 feet long and 1/8 inch wide. This was wound in a spiral on a copper tube. When this was arranged with water-jacket and magnetizing coil, the magnetization was not exactly transverse. Lord Kelvin calculated that the lines of flow in the iron were at an angle of 84° with the magnetic lines of force. An increase of resistance was observed. Later experiments with small squares of iron placed on a copper "cradle" between the poles of a powerful Ruhmkorff magnet showed that an accurately transverse magnetic field decreases the resistance of iron. The results of later experiments on a small iron bar confirm these observations. Lord Kelvin also discovered that in a bar of nickel the results were similar to those in iron. He observed a decrease of resistance of 1 part in 192 for transverse magnet-

ization, and an increase of about 1 part in 144 for longitudinal magnetization.

Though the account of Lord Kelvin's experiments prove them to be work of a very high order, the results can be regarded as only qualitative as far as furnishing a basis for theoretical deductions. This arises from lack of data on the strength of the magnetic fields employed, and is doubtless due to the fact that the experiments antedate by several years the adoption of the c.g.s. absolute system of units. In the case of the longitudinal magnetization it would be possible to calculate the field with some accuracy from the dimensions of the coil as given if the current strength were known. This is given as the current from "six small iron cells", which makes such a calculation valueless. In the cases in which the magnet was used there is no way of even estimating the field.

Tomlinson, in 1875, published a preliminary report on investigations with magnetized iron and steel. Some of his results were contradicted subsequently and need not be mentioned here. His later work (Phil. Trans. 1883, part 1, p. 133, et seq.) is a part of a very exhaustive article covering his experiments on "The Influence of Stress and Strain on the Action of Physical Forces". As the title indicates, he was investigating primarily the influence which stress and strain might have on the change of resistance produced by magnetization. The resistance was measured by the Wheatstone's Bridge method; in many cases the alteration in the resistance was measured by the deflection of the galvanometer.

His results may be summarized as follows. By longitudinal magnetization, the resistance of an annealed iron wire was

increased from 0.039% to 0.053%, depending on the strength of the field. A steel knitting needle, tempered and hardened, showed an increase of 69.8 x 10^{-10}% per unit of magnetizing force. It also showed a permanent alteration in its resistance due to the residual magnetization. Hardened piano wire gave similar though smaller results, while a second knitting needle gave nearly twenty times as great a change. Tests on small nickel and cobalt bars showed an increase of 43.43 x 10^{-12} per cent per unit of magnetizing force in the former, and 6.28 x 10^{-12} per cent per unit of magnetizing force in the latter. Zinc foil showed no effect when placed in the magnetizing coil, owing to the weakness of the field. When the field was increased by wrapping the foil on an iron core, an alteration of 0.0148% was observed. In this case the magnetizing force could not be estimated owing to the presence of the iron. In bismuth the change was of the order of 21 x 10^{-8} per unit of resistance per unit of magnetizing force. Copper wire was tested with a "comparatively strong magnetizing force - more than 480 times the strength of the earth's field". The results showed that the change, if any, was less than 1 part in 4 million.

Schuster and Stewart's results (Phil. Mag.,vol. 164, pp. 535-541, Jul.- Dec. 1874.) show a decrease of resistance in copper due to magnetization. The wire tested forms one arm of a Wheatstone's Bridge, and is wound around the pole pieces of an electromagnet. Tomlinson explains the momentary effect which Schuster and Stewart observed as due to the decrease in self-induction of that arm of the bridge when the magnet is excited. His criticism seems valid.

Tomlinson concludes from his results that the change of

resistance of iron and steel wires depends more upon the magnetizing force than on the magnetism induced. He suggests that the change may be represented by the formula

$$y = a \cdot \alpha + b \cdot \beta$$

where α is proportional to the magnetizing current and β to the magnetism induced. He also offers the following ingenious explanation of the observed results:- "The increase of resistance which is produced by magnetization is probably not due merely to the rotation of the molecules of the magnetized substance as molecules, but to the electrical currents which, according to Ampere's hypothesis, are constantly circulating in the molecules".

Though Tomlinson's results are of unquestioned accuracy, they are of little value for theoretical purposes. It is difficult if not impossible to estimate accurately the strengths of the fields used, but they were probably quite weak. This conclusion is justified by his statement that a field of "considerable strength" was "480 times the earth's field" - probably not over 100 lines per square centimeter at best.

The work of Goldhammer (Wied. Ann. Vol. XXXI, p. 360, 1887.) deals with other metals besides iron, cobalt, and nickel, and hence is of considerable interest. In order to avoid any mechanical deformations due to magnetization, he worked with films deposited electrolytically upon glass. The resistances were measured by the Wheatstone's Bridge method. To increase the sensitiveness, a second slide wire was used , as shown in Figure 1. This increased the sensitiveness 113 fold but did not increase the absolute accuracy of the apparatus. He claims an accuracy of

.005 % to .01 %.

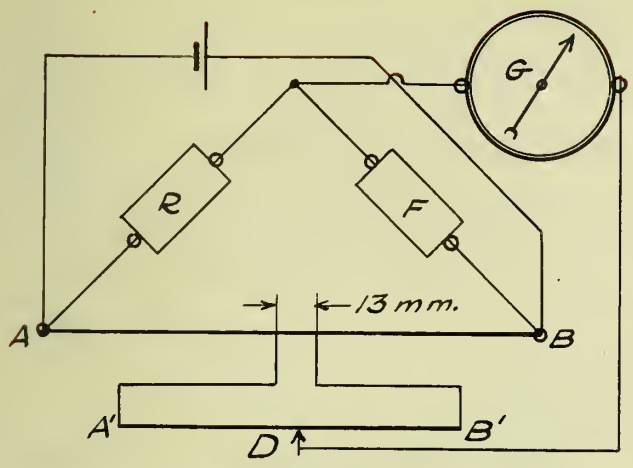


FIG. 1.

Bismuth, tellurium, antimony, cobalt, nickel, and iron were tested with both transverse and longitudinal magnetization. The fields were obtained from a large electromagnet. In each case the length of the air-gap and the strength of the magnetizing current are specified, but the actual strength of the magnetic field is not given. The following table is compiled as representative of his results.

Metal	Thickness	Resistance	Per cent change in Resistance	
			longitudinal	transverse
Bismuth	.02-.03mm.	0.75 S.E.	0.09	0.15
Tellurium	"	2.00 S.E.	0.054	0.014
Antimony	"	0.4 S.E.	0.025	0.02

Experiments were made with bismuth, having the field at various angles from 0° to 90° with the lines of flow. These showed that the change in the effect varied continuously with the angle between the lines of field and the lines of flow. These results he represents graphically as shown in Figure 2.

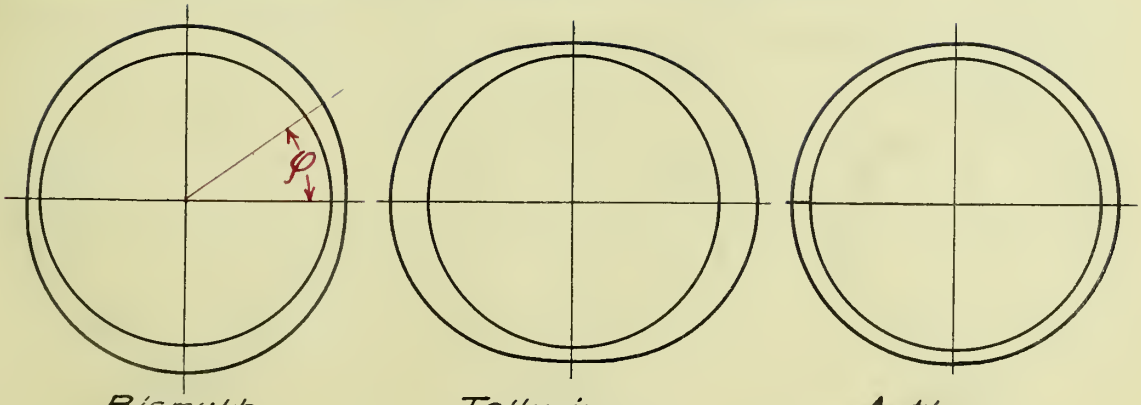


FIG. 2.

The X axis represents the direction of the magnetic field; φ represents the angle between the lines of force and the lines of flow; the length of the radius vector represents the resistance along the vector. When there is no field, the resistance along all vectors is the same, giving a circle; but as magnetization alters the resistance differently along different vectors, the circles are changed to ellipses.

Goldhammer's results for nickel and cobalt are similar. Transverse magnetization produced an increase of resistance in each, while longitudinal magnetization caused a decrease of resistance. The decrease in cobalt was less than that in nickel. His observations on iron confirm those of Lord Kelvin, He does not claim as great accuracy for these results as for those on cobalt and nickel.

Since the effects of transverse and longitudinal magnetization are of opposite sign, it should be possible to find a position for which magnetization would produce no effect. This was verified for nickel and cobalt by experiment. With nickel this occured when the lines of flow made an angle of approximately 70° with the lines of field. With cobalt the neutral position was between $\varphi = 30°$ and $\varphi = 60°$. As with bismuth, antimony, and tellurium, the results were shown graphically as in Figure 3.

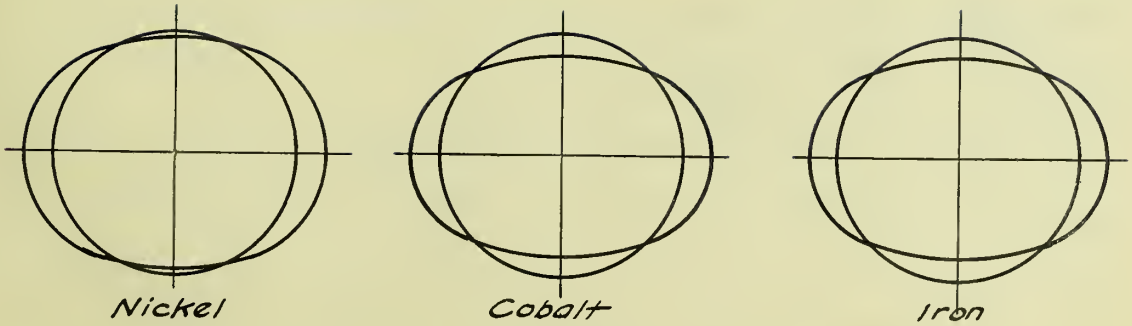


FIG. 3.

Lenard (Wied. Ann. vol. 39, p. 619, 1890.) has made a very exhaustive study of the resistance of bismuth to both direct and alternating currents when in a magnetic field. His work is of great interest as it deals with the development of the Bismuth Spiral as a means of measuring magnetic fields. The discussion of this phase of the subject is beyond the limits of this paper. His main conclusions are as follows:- For 300 oscillations per second, the resistance of bismuth wire is the same as for constant current. For periods of the order of 10,000 oscillations per second, the resistance to alternating currents is smaller than that for direct currents under similar circumstances, whether out of the field or in the field parallel to the lines of force. For transverse fields greater than 6,000 lines per square centimeter, the resistance to alternating currents is greater than the resistance to direct currents. Iron, antimony, and tellurium show slight differences in their resistances to direct and to alternating currents, but copper and german silver do not.

Gray and Jones in 1900 (Proc. Roy. Soc. vol. 67, 1900, pp. 208-216.) published the results of an investigation of the change of resistance of iron when magnetized longitudinally. They measured not only the increase in resistance ($\Delta\varphi$), but also the magnetization (I). The curves for increase of resistance ($\Delta\varphi$, H), and magnetization (I, H) were plotted. From the similarity between these curves they suggested that the change in resistance probably depended upon the magnetization rather than on the magnetizing force. This conclusion is exactly the opposite of that of Tomlinson. (see page 5.)

Beattie (Phil. Mag., vol. 211, pp. 343-353.) has inves-

tigated the effects of transverse magnetic fields on the resistance of iron, cobalt, and nickel. These were in the form of films deposited electrolytically on platinized glass. He measured, for various field strengths, both the Hall effect, which is proportional to the magnetization, and the change of resistance. The film was connected as one arm of a Wheatstone's Bridge mesh, and the change in resistance was calculated from the galvanometer deflection. The field strength was measured by the rotation of the plane of polarization in glass. With pole pieces 10 mm. in diameter and an air-gap of 3 or 4 mm., the field was varied from 2,000 to 16,000 lines per square centimeter. In each case a decrease in resistance was observed.

His results were as follows:- The greatest change occurs in nickel. This change is noticeable with fields as low as 1,000 lines. In some nickel films the resistance increased at first but decreased with higher fields. In cobalt the change could be detected for fields not less than 2,000 lines. In these films the change of resistance was proportional to the square of the Hall effect, and hence proportional to the square of the magnetization. The change of resistance in the iron films was less than that in the films of cobalt and nickel. No alteration in resistance could be detected with certainty for fields less than 6,000 lines, and the change is less than it would be if iron followed the same law as cobalt.

Various other investigators have worked along this line, many of them with especial reference to the effect in bismuth. Their work, with two exceptions, adds little to the results already quoted except in helping to perfect the Bismuth Spiral. These

two exceptions are Patterson and Grunmach. Their work is very comprehensive in scope and is of great accuracy.

The work of Patterson (Phil. Mag. vol. 219, pp. 643-656, 1902.) was undertaken at the suggestion of Professor J. J. Thomson to test certain deductions from the electron theory. The investigation was carried on in the Cavendish Laboratory. His samples were in the form of double silk-covered wires. These were wound in flat spirals about 15 mm. in diameter, dipped in paraffin, and mounted between mica plates. The finished spirals were only a trifle over 1 mm. thick. Two identical spirals were made from each sample. One was placed in the field and was connected to a Wheatstone's Bridge mesh of which the other spiral formed the compensating arm. The other two arms of the bridge were german-silver coils of approximately the same resistance as the test spiral. A variable resistance was connected in parallel with one of the arms to balance the bridge. The galvanometer was of the D'Arsonval type. It had a resistance of 95 ohms, and gave a deflection of 1 millimeter when one of the arms was altered by 1 part in 50,000. The field was produced by an electromagnet of the Du Bois type. The air-gap was usually 2 mm. The field was measured with a bismuth spiral. The poles of the magnet,and all the coils except the one in the field, were surrounded by water baths. Throughout the experiments great care was taken to insure accuracy.

No effect was observed in german-silver. This contradicts the observations of Lenard. Patterson suggests that this discrepancy may be due to a difference in the composition of the samples used. Accurate results with copper were difficult to obtain owing to the heating effect of the current through the bridge.

The change in resistance due to this heating effect was in such a direction as to conceal the change due to magnetization. Results such as .0047 ohms, .0050 ohms, .0047 ohms were obtained as the change in a spiral of 24.04 ohms resistance due to a field of 27,650 lines per square centimeter.

In the remainder of Patterson's experiments, the samples were wound bifilar on mica strips about 14 x 13 x 1/10 mm. The water bath was not needed with these. Mercury was tested in a spiral of capillary tubing. In each case the resistance was increased by a transverse magnetic field. The metals tested, in the order of the magnitude of the effect, were cadmium, zinc, mercury, carbon, gold, silver, copper, tin, and platinum. The effects in silver and copper were nearly equal. The results show that the change in resistance is proportional to the square of the magnetic field producing it.

To test the effect of longitudinal magnetization, several coils were wound on mica. These were piled one above another and joined in series. They could then be placed in the field without increasing the air-gap unduly. The metals tested,in the order of the magnitude of the effect, were zinc, copper, silver, and tin.

In some later work on the electrical properties of very thin metallic films (Phil. Mag., vol. 220, Dec. 1902, p. 670.) Patterson subjected some of his films to a transverse field. With films of platinum or silver, the change was slightly less than that observed in wires, though of the same order of magnitude. With bismuth films, the alteration was small compared to that obtained for the metal in the form of wire. The magnitude of the effect decreased rapidly if the thickness was decreased below a certain

value.

The most recent work along this line is that of Grunmach (Phys. Zeitschrifte, 7, pp. 729-740, Oct. 1906.) He investigated the effect of transverse magnetization on the resistance of silver, platinum, tantalum, cadmium, tin, gold, palladium, zinc, copper, lead, cobalt, nickel, and iron. These were in the form of thin wires, wound in flat, bifilar spirals, imbedded in wax and protected by thin plates of hard rubber. The field was obtained from a Du Bois magnet, and was measured by means of a carefully calibrated bismuth spiral. The apparatus for measuring the change in resistance was essentially a differential galvanometer, the test spiral being part of one of the opposed circuits. Readings were taken for various strengths of field up to 16,000 lines per square centimeter. From these data a curve was plotted for each sample, using field strengths as abscissas and the change in resistance divided by the original resistance as ordinates.

These curves show a marked difference in behavior between the ferromagnetic metals and the diamagnetic and paramagnetic metals. The results with the latter are similar to those obtained by Patterson. In each case the resistance increases continuously with increasing field. The metals tested, arranged in the order of the magnitude of the effect, are cadmium zinc, silver, gold, copper, tin, palladium, lead, platinum, and tantalum. This is the same order that Patterson obtained except that his results placed gold ahead of silver. The change of resistance of tantalum was very small, even for fields of 16,000 lines.

The ferromagnetic metals show a very different behavior. Three of the four samples of iron show an increase of resistance for weak fields. This reached a maximum for a field strength of

about 4,000 lines. The curve then bent down and crossed the axis at approximately 8,000 lines. For fields above 8,000 lines per square centimeter the resistance was decreased. Nickel gave similar results except that the curve crossed the axis at about 600 lines. This confirms the observations of Beattie on nickel films which were mentioned on page 9. The cobalt sample and one of the iron samples showed a continuous decrease in resistance for increasing fields.

Theoretical Discussion.

The theory of the conduction of electricity through metals as worked out by J. J. Thomson (Rapports presentes au Congres International de Physique, vol. 3, pp. 138-151, Paris, 1900.) may be outlined as follows. Every metal contains an enormous number of electrons - Thomson calls them corpuscles - each bearing a negative charge. The electrons are identical in all metals. The negative charge which each bears is of the same order of magnitude as that carried by an hydrogen ion in electrolysis, but the mass of the electron is only 1/1000 that of the hydrogen atom, approximately. These electrons move about at random through the metal. Their movements under ordinary conditions resemble those which the molecules of a perfect gas execute according to the Kinetic Theory of Gases. The electrons have a mean free path, λ, an average velocity, c, and a mean time of freedom. The collisions which determine the time of freedom of the electron take place, not between two electrons, but between an electron and a neutral molecule of the metal. When an electric force is applied, the electrons acquire a steady drift under its action. The electrons in a metal exert a pressure just as the molecules of a gas exert a pressure on the walls of the containing vessel. This pressure, if greater than that of the atmosphere, will tend to force out those electrons which are near the surface. However, when an electron is torn from a molecule, it leaves the molecule positively charged. Hence as the electrons are forced out, the outer layer of molecules will become positively charged. The attraction of these positively charged molecules will prevent the separation of the electrons from the surface.

If we have the electrons moving in the xy plane under the action of a steady electric force, X, in the direction of the x axis, and then apply a magnetic field at right angles, the equations of motion are

$$m\frac{d^2x}{dt^2} = eX - He\frac{dy}{dt}$$

$$m\frac{d^2y}{dt^2} = He\frac{dx}{dt}$$

where m = the mass and e = the charge of an electron, and H is the perpendicular magnetic field. When $x = 0$, $\frac{dy}{dt} = 0$. Hence on integrating (2) we have

$$\frac{dy}{dt} = \frac{He}{m}x$$

Substituting this in (1) and dividing through by m gives

$$\frac{d^2x}{dt^2} = X\frac{e}{m} - \frac{H^2e^2}{m^2}x$$

To solve this equation we multiply both sides by $2\left(\frac{dx}{dt}\right)$ giving

$$2\left(\frac{dx}{dt}\right)\left(\frac{d^2x}{dt^2}\right) = -2\frac{H^2e^2}{m^2}x\frac{dx}{dt} + 2\frac{Xe}{m}\frac{dx}{dt}$$

Integrating this equation and extracting the square root of both sides gives

$$\frac{dx}{dt} = \sqrt{-\frac{H^2e^2}{m^2}x^2 + 2\frac{Xe}{m}x + c^2}$$

where c represents the velocity with which an electron commences its free path. Separating the variables we have

$$\frac{dx}{\sqrt{\left(-\frac{H^2e^2}{m^2}x^2 + X\frac{2e}{m}x + c^2\right)}} = dt$$

On integrating this equation we have

$$\frac{1}{\sqrt{\frac{H^2e^2}{m^2}}}\sin^{-1}\left(\frac{\frac{2H^2e^2}{m^2}x - 2X\frac{e}{m}}{\sqrt{4X^2\frac{e^2}{m^2} + 4c^2\frac{H^2e^2}{m^2}}}\right) = t + c'$$

When $t = 0$, $x = 0$. Hence

$$c' = \frac{m}{He}\sin^{-1}\left(\frac{-X}{\sqrt{X^2 + c^2H^2}}\right)$$

Substituting the value of c' and solving for x gives

$$x = \sum \frac{e}{m} \cdot \frac{m^2}{H^2 e^2} \left(1 - \cos \frac{He}{m} t\right) + \frac{c\,m}{He} \sin \frac{He}{m} t$$

The velocity at time t along the x axis is

$$\frac{dx}{dt} = \sum \frac{e}{m} \cdot \frac{m}{He} \sin \frac{He}{m} t + c \cos \frac{He}{m} t$$

If the interval of time, T, between two collisions is very small, $\frac{He}{m} T$ is very small. Hence we may substitute, as a very close approximation, (see note below *)

$$\sin \frac{He}{m} T = \frac{He}{m} T - \frac{1}{\lfloor 3} \frac{H^3 e^3}{m^3} T^3$$

$$\cos \frac{He}{m} T = 1$$

This substitution gives

$$\frac{dx}{dt} = \sum \frac{e}{m} \cdot \frac{m}{He} \left(\frac{He}{m} T - \frac{1}{\lfloor 3} \frac{H^3 e^3}{m^3} T^3\right) + c$$

or

$$\frac{dx}{dt} - c = \sum \frac{e}{m} \left(T - \frac{1}{6} \frac{H^2 e^2}{m^2} T^3\right)$$

But $\left(\frac{dx}{dt} - c\right)$ is the change in velocity due to X in time T.

The average change during this time is

$$\frac{1}{T} \int_0^T \sum \frac{e}{m} \left(T - \frac{1}{6} \frac{H^2 e^2}{m^2} T^3\right) dT$$

or

$$\sum \frac{e}{m} \left(\frac{T}{2} - \frac{1}{24} \frac{H^2 e^2}{m^2} T^3\right)$$

If we place $u_0 = \frac{1}{2} \frac{e}{m} T$, this expression becomes

$$\sum u_0 \left(1 - \frac{1}{3} H^2 u_0^2\right)$$

If δu_0 is the change in velocity due to the magnetic field,

$$\delta u_0 = -\frac{1}{3} H^2 u_0^3$$

* If the terms above the first power in the value of the cosine are disregarded, it would seem that the term in the value of the sine which involves the third power should be neglected also. However, the above approximation seems to be the only one which will give the result which Thomson states in his article. On the other hand, the square of (H e T)/m might be negligible in comparison to unity while its cube could not be neglected when compared to the first power.

Hence $$\frac{\delta u_o}{u_o} = -\frac{1}{3} H^2 u_o^2$$

If σ is the resistance

$$\frac{\delta \sigma}{\sigma} = \frac{1}{3} H^2 u_o^2$$

That is, the ratio of the change of resistance to the original resistance is proportional to the square of the field strength. The results obtained by Patterson confirm this deduction. (see page 11)

From the equation

$$\frac{\delta \sigma}{\sigma} = \frac{1}{3} H^2 u_o^2$$

it is easy to deduce the value of u_o when the strength of the magnetic field and the effect which it produces are known.

The specific conductivity is

$$n \cdot e \cdot u_o$$

Hence, if u_o and the specific conductivity are known, the value of $n \cdot e$ may be deduced.

It has been calculated that if N is the number of hydrogen molecules in 1 c.c. of air at 0° C. and 760 mm. pressure, then

$$N \cdot e = 0.4$$

Since the electrons are assumed to obey the laws of perfect gases, and e for an electron equals e for an hydrogen ion, it follows that $N \cdot e = 0.4$ when N is the number of electrons per c.c. The pressure in atmospheres exerted by the electrons is

$$P = \frac{n \cdot e}{N \cdot e}$$

From this equation Thomson calculates that the electrons in bismuth exert a pressure of about 1/4 atmosphere. In a similar way Patterson calculates from his observations that the pressures exerted by the electrons in the various metals tested by him are as follows, the pressures being given in atmospheres.

Platinum	700	Copper	1730
Gold	1115	Zinc	293
Tin	225	Cadmium	136
Silver	1840	Mercury	21

Carbon 0.54

As noted on page 14, this pressure tends to drive the electrons out of the metal, but they do not escape on account of the attraction of the outer layer of positively charged molecules. The work necessary to bring an electron from this outer layer into the interior of the metal against the pressure of the electrons in the interior is the contact potential of the metal. Hence it is possible to calculate the contact difference of potential between two metals from the alteration of their respective resistances by a magnetic field. In this way Patterson calculates the contact difference of potential for various combinations. His results are not in accord with the usually accepted values, but in general the relative magnitudes are similar.

The electron theory is also confirmed by the results of Patterson's work on thin films. Thomson has shown (Proc. Cam. Phil. Soc.,vol.11, p. 120, 1901.) that when the thickness of a film of metal is less than λ , the free path of the electron, the resistance of the film should be much greater than would be calculated from its dimensions. Also the effect of magnetic fields on the resistance should be greatly diminished. Patterson's results (see page 11) confirm these deductions.

The theory as outlined above fails to account for the decrease in resistance which the ferromagnetic metals undergo in a magnetic field. This has been discussed quite recently by E. P.

Adams (Phys. Rev., vol 24, pp, 428-435, 1907.) He suggests two modifications of the theory. First, the magnetic field produces a rearrangement of the molecules of the metal. This alters the mean free path of the electron, and therefore alters its time of freedom. Second, the collisions, instead of occuring only between an electron and a neutral molecule, take place between two electrons, and are analogous to the collisions between hard elastic spheres. With these modifications he finds that the change of resistance is expressed by the equation

$$\frac{\delta\sigma}{\sigma} = \frac{\delta T}{T} - \frac{1}{4} H^2 \frac{e^2}{m^2} T^2$$

where δT is the alteration in the time of freedom.

For the change in resistance to be an increase, δT must be positive, and $\frac{\delta T}{T}$ must be greater than $\frac{1}{4} H^2 \frac{e^2}{m^2} T^2$ Since for diamagnetic and paramagnetic bodies the susceptibility is practically constant, it is probable that the change in the configuration of the molecules, and hence the change in T, will increase with increasing field. Therefore the change in resistance will be in the same direction for all fields. The experiments of Patterson and Grunmach confirm this deduction.

With the ferromagnetic metals the change in configuration of the molecules can proceed only to the point of saturation. Above this point the term $\frac{\delta T}{T}$ becomes constant but the term $-\frac{1}{4} H^2 \frac{e^2}{m^2} T^2$ will continue to increase as the square of the field. Hence we may expect the change in resistance to reverse in direction for higher fields. This is in accord with the observations of Grunmach on iron and nickel wires.

Investigations on Electrolytes.

The effect of a magnetic field on the resistance of an electrolyte was first investigated by Neesen (Wied. Ann. vol. 23, pp. 482-493, Oct. 1884.) He used the Wheatstone's Bridge method with a direct current. The two ratio arms of the bridge were made equal. The other two arms consisted of similar glass tubes of unequal length. These were filled with a solution of ferrous sulphate. Iron electrodes were used. The bridge was balanced by means of a resistance box connected in series with the shorter tube. By this arrangement the effects of polarization at the electrodes were eliminated or compensated. The shorter tube was placed between the poles of a "suitable electromagnet", and the field generated by "three Bunsen elements" was thrown on. No effect was observed when the field was perpendicular to the current. With the field parallel to the current, a slight decrease in resistance was observed. Berndt points out in his article, to which reference is made a little later, that the effect observed by Neesen was probably due to the influence of the magnetic field upon the polarization of the electrodes. With iron electrodes, this might well be the case.

A preliminary report by Bagard (Comp. Rend.,vol. 128, pp. 91-93, 1899.) gives the results of some experiments on a 1/4 normal solution of copper sulphate. His method consisted essentially in measuring the current which flowed through the electrolyte due to a constant difference of potential. The current was measured by means of a sensitive D'Arsonval galvanometer placed in parallel with a low resistance in series with the electrolyte. The electrolyte was contained in a ring shaped vessel. This was placed

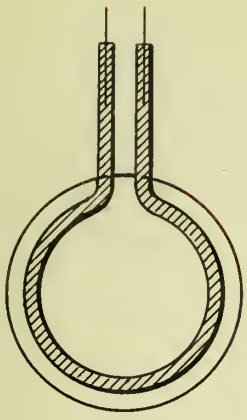


FIG.4.

between the poles of a large electromagnet as shown in Figure 4. The tubes containing the electrodes were long enough to place them outside the direct influence of the field.

In a transverse field of 5,000 lines per square centimeter, an increase of resistance was observed. This varied from 0.94% to 1.4%, depending on the directions of the field and the current. This result is explained by Bagard by the electrodynamic action of the field on the current. This action throws the liquid against either the outer or the inner walls of the ring. In either case the cross section of the conductor is reduced, and therefore the resistance is increased. If the liquid is thrown toward the outer walls of the tube, the mean length of the conductor is increased. This produces an additional increase in resistance. If the liquid is thrown against the inner wall, the average length is decreased. This tends to decrease the resistance. Since the observed increase in resistance is greater when the force exerted on the ring is centrifugal, this seems to be the true explanation. Bagard concludes that the resistance as a whole is affected in this mechanical way, but that the specific resistance is unaltered.

The only other work that has been done along this line is that of Berndt. The account of his investigations was published (Ann. d. Phys., vol. 23, pp. 932-950, 1907.) soon after the author's investigation was commenced. His investigation was very comprehensive in scope, and his experimental work has the appearance

of being very accurate. He investigated the effects of both transverse and longitudinal fields upon the resistance of solutions of ferrous sulphate, iron chloride, nickel sulphate, nickel nitrate, cobalt nitrate, bismuth nitrate, potassium-antimony tartrate, and copper sulphate. He also made similar experiments upon mercury and molten bismuth. The electrolytes were contained in small, H - shaped cells. To insure constant temperature throughout the experiment, the cell was immersed in a bath of ether maintained at the boiling point by means of a special electrical heating coil. The mercury and bismuth were enclosed in capillary tubes and similar precautions were taken to insure constant temperature. To avoid any electrodynamic or polarization effects, the Kohlrausch method was used. Berndt says that the telephone which he used was exceptionally sensitive. He claims an accuracy of 1/250 % for the results with electrolytes.

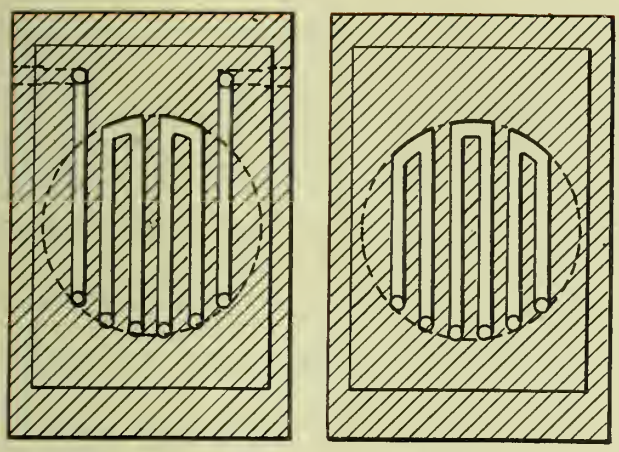
The transverse fields were as high as 3040 lines per square centimeter, and the longitudinal fields were usually 1020 lines per square centimeter. Negative results were obtained in all cases. Melted bismuth at 365°C and mercury gave similar results. With these metals, a direct current was used. The accuracy claimed for the results with mercury is 1/20,000 %, while for bismuth the change, if any, was less than 1/660 %. This slight apparent effect in molten bismuth was attributed to the direct magnetic action of the current.

Description of the Apparatus and Method used by the author.

The magnetic field was obtained from a large electromagnet of the Du Bois type. For these experiments it was provided with special conical pole pieces with faces 25 mm. in diameter. The current was obtained from the 110 volt D.C. dynamo and was controlled with water rheostats. The field strength was measured with a Hartmann and Braun bismuth spiral. The calibration curve furnished by the makers extends only to 16,000 lines per square centimeter. No deviation from a straight line can be discovered above 6,000 lines. It was assumed that this linear relation between $(R - R_o)/R_o$ and the field strength held above 16,000 lines. The fields for values of $(R - R_o)/R_o$ greater than 0.8 were extrapolated on this assumption. In the copy of the calibration curve included with this paper, the extrapolated portion is shown by the dotted line. For convenience in getting the field for any current, a curve was plotted showing the relation between magnetizing current and field strength for each of the air gaps used.

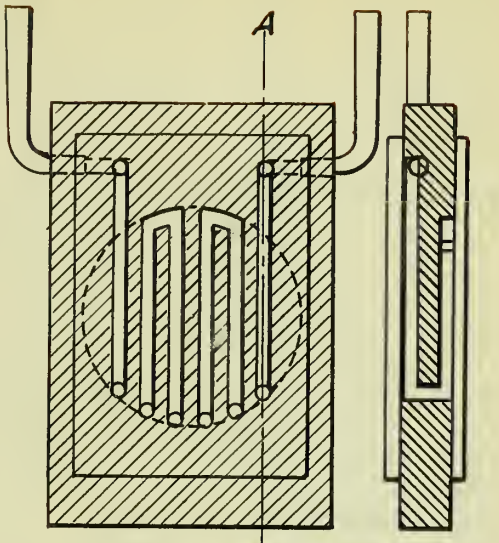
The electrolytes tested were enclosed in small cells which were made as follows. The basis of the pair of cells was a piece of hard rubber about 115 mm. long, 35 mm. wide, and 6.5 mm. thick. On each side of this, a number of rectangular grooves were cut by a milling machine. The grooves on one side were exactly opposite the corresponding grooves on the other, and were of fairly uniform cross-section throughout. In the first pair of cells, eight grooves, approximately 1.5 mm. x 1.5 mm., were cut in each face. In the second set of cells, six grooves, 2 mm. x 2 mm., were cut in each face. In both cases the grooves were confined to a

strip less than 25 mm. wide. The rubber base was cut in two, and each half was finished up in as nearly the same way as possible. In the center of each side, a circle about 25 mm. in diameter was described. The circles were exactly opposite each other. Holes of the same diameter as the width of the grooves were drilled through the rubber around one half of the circle, as shown in Figure 5. Around the opposite semicircle small cross cuts were made through alternate ridges to connect the grooves. These were spaced on opposite sides so that a continuous passage was formed from the extreme groove on one side to the extreme groove on the other side of the same face. The arrangement can be understood from Figure 5. This figure shows both sides of a cell. The parts of the grooves not included in the circles were filled with de Khotinsky's cement, except the outside grooves on one face. These were left clear a few millimeters farther at the upper end. A hole about 3 mm. in diameter was drilled in each edge to communicate with the upper end of each of these longer grooves. Pieces of glass tubing of about 5.5 mm. inside diameter were bent into the shape of an L. These were to receive the electrodes. The vertical arm was about 35 mm. long. The horizontal part was drawn out so as to fit snugly into the holes drilled in the edge of the cell, and was about 15 mm.long. The tubes were cemented firmly in place with de Khotinsky's cement. A piece of cover glass was cemented to each face of the cell to complete it. The cell was mounted on a stiff wire in the middle of a rectangular base. A mercury cup was mounted at each end. Platinum electrodes, 19 mm. x 4 mm. x 0.03 mm., provided with rubber caps to fit the ends of the glass tubes, made connections with the mercury cups. The whole arrangement is shown in Figures 6 and 7.



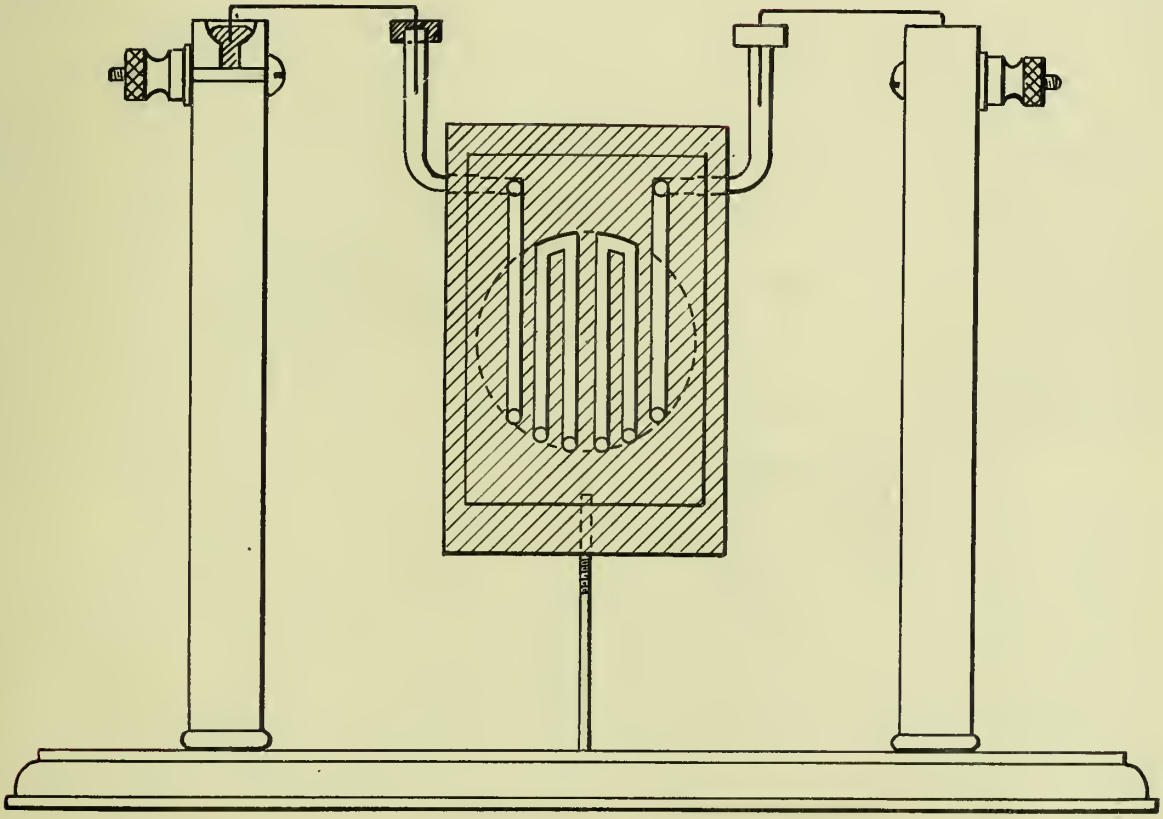
Front Back

FIG. 5.



Front Section A-B

FIG. 6.



The Cell Mounted.

FIG. 7.

The finished cells were about 10 mm. thick. These cells were easily filled with the electrolyte by attaching one tube to an aspirator and dipping the other into the liquid.

An aperiodic D'Arsonval galvanometer of the Ayrton-Mather type, made by Paul, was used throughout the investigation. Its resistance was 307 ohms. A current of 1.38×10^{-8} amperes caused a deflection of 1 mm. on a scale at a distance of 115 cm. The galvanometer was mounted on a bracket attached to an inside stone wall. It was entirely free from mechanical jars. Experiment showed that the electromagnet did not affect the galvanometer.

The resistance boxes used were the best grade manufactured by Hartmann and Braun.

It was decided to use a direct current method for measuring the resistance as it was thought that the use of an alternating current might hide the effect sought. Toward the last of the investigation an attempt was made to check some of the results by means of an alternating current and telephone. This proved futile owing to the exceedingly high resistances used. The Wheatstone's Bridge method was used throughout the experiments.

At first the method of Meesen was tried. Two cells which were practically duplicates were used as two of the arms of the bridge. One cell was placed between the poles of the magnet, while the other was placed at a distance so as to be entirely out of the field. The other two arms were resistance boxes. They were always kept equal. The bridge was balanced by connecting one or more resistance boxes in series with the cell having the smaller resistance. The current from a storage battery was led in so as to divide between the two cells. (see Figure 8.) It was hoped

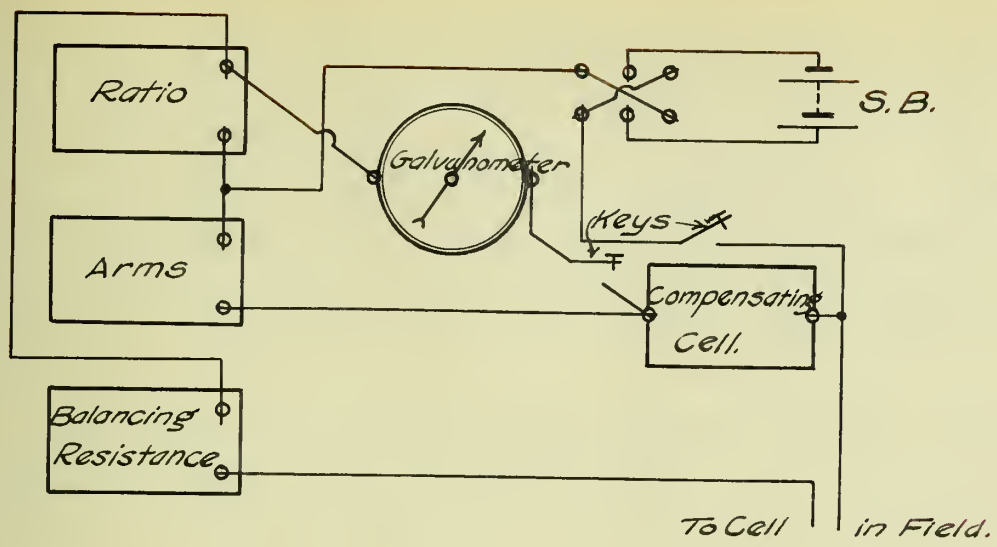

Ratio
Arms
Balancing
Resistance
Galvanometer
S. B.
Keys
Compensating
Cell.
To Cell
in Field.

FIG. 8

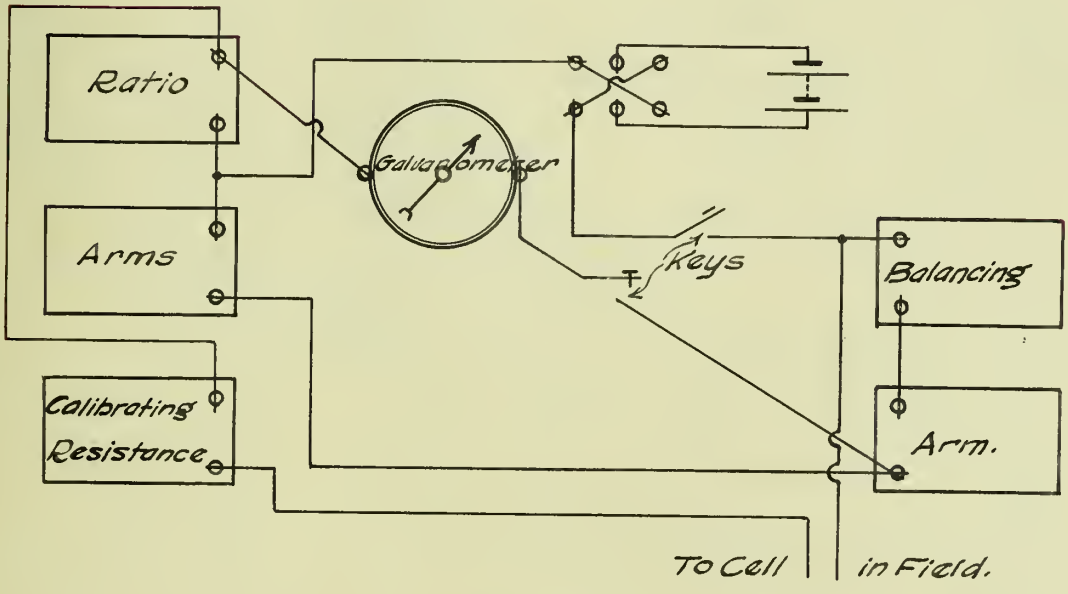

Ratio
Arms
Calibrating
Resistance
Galvanometer
Keys
Balancing
Arm.
To Cell
in Field.

FIG. 9

that by this arrangement the effects of polarization in the two cells would largely offset each other. Since the resistances were very high - from 100,000 to 500,000 ohms - a potential difference of from 20 to 50 volts was used. With such large resistances and e.m.f.'s, any uncompensated polarization of the electrodes should be negligible.

This method proved very unsatisfactory. It was practically impossible to obtain a balance, as the galvanometer index would wander from one side of the zero position to the other in a most erratic and annoying fashion. Several weeks were spent in trying to discover the cause of this unsteadiness. At first it was ascribed to sudden slight changes in temperature. To avoid these, each cell was placed in a box of heavy pasteboard and carefully packed in cotton batting. The box containing the cell which was placed in the magnetic field was cut away on both sides to admit the pole pieces of the magnet. This did not permit it to be quite as well protected as the other cell. On the other hand, the large pole pieces very near it would have a tendency to preserve a uniform temperature without further protection.

The resistances used were very high, often as much as half a megohm or more. This suggested that the insulation might be at fault, and extra precautions were taken to insure that no leakage occured. The top of the table, upon which most of the apparatus stood, was covered with sheets of hard rubber. The galvanometer was insulated in a similar manner. The stool on which the observer sat during the experiments was provided with insulating feet. Wherever a connecting wire came in contact with anything, rubber or porcelain insulation was used.

It was thought that possibly the small cross-section of the electrolyte rendered the resistance excessive, and accordingly the second pair of cells mentioned above was made. All these precautions proved futile. The behavior of the galvanometer was quite as erratic as ever. No satisfactory explanation of its behavior has been found.

In attempting to measure the resistance of one of the cells by substituting resistance boxes for the compensating cell, it was found that the galvanometer was very steady. An almost perfect balance was easily obtained by keeping the battery circuit closed continuously. This suggested a new line of attack. The compensating cell was replaced by suitable resistance boxes. Both the battery and the galvanometer circuits were closed permanently by knife switches. The bridge was then balanced by means of the resistance boxes in the fourth arm. As might be expected, the resistance of the electrolyte gradually changed. This caused a gradually increasing galvanometer deflection, but the deflection changed quite slowly and, as a rule, the changes were quite uniform.

The final method of taking observations was as follows. The bridge was balanced as described above. The galvanometer deflection was read at half minute intervals for 5 minutes. The magnetic field was then thrown on for 1 1/2 or 2 minutes, and readings were taken during this interval every half minute as before. The field was thrown off and the observations were continued for 5 minutes more before the effect of the field was again tried. Usually the field was thrown on three or four times during a set of observations. The value of 1 mm. change in deflection in ohms was determined before the observations were commenced by plugging out 200

or more ohms in the resistance box connected in series with the cell. (see Figure 9.) This determination was repeated at the close of the set of observations.

The resistance of the electrolyte at half minute intervals was calculated on the assumption that the change in resistance was proportional to the change in deflection. This assumption is not stirctly valid, but for small changes it is easily shown to be a very close approximation. In this case no difference could be observed between the change in deflection produced by a change in resistance of from 200 to 2,000 ohms at the beginning and at the end of a series of observations. This shows that the error introduced by the assumption is less than the experimental error of the method.

A curve was plotted from each set of data, using times as abscissas and resistances as ordinates. A study of these curves shows that, as a rule, the magnetic field produces a sudden alteration in the resistance of the electrolyte. When the field is removed, the cell recovers more or less rapidly and the curve continues in the same general direction that it had before the field was thrown on.

Cobalt chloride, ferric chloride, and copper sulphate were chosen as representative electrolytes. Kahlbaum's highest purity salts were used. The strength of the solution in each case was very approximately 1/100 molar. From four to six sets of observations were taken with each in a transverse field. As a rule a set of observations was taken with the current flowing in one direction. The cell was then emptied and refilled with fresh solution. The electrodes were cleaned with hydrochloric acid and

distilled water, and then heated to redness. The cell was again placed in position and from 30 minutes to several hours were allowed to elapse to insure thermal equilibrium. The current for the second set of observations flowed through the cell in direction opposite to that of the first set. In most of the observations, the direction of the magnetic field was reversed each time it was thrown on. In the accompanying curves, the readings taken when the electrolyte was under the influence of the magnetic field are denoted by a double circle (◎). When the field is in the direction denoted for convenience as "reversed", the double circle contains a cross (⊛).

Experiments were also made with fields parallel to the direction of the current through the liquid. The electrolyte was enclosed in a long glass cell which slipped through special pole pieces. These were of the same shape as those used in the previous experiments, but a hole, just large enough to admit the horizontal part of the cell, was bored through the center of each. The general arrangement is shown in Figure 10. The diameter of the horizontal tube was 3 mm. (inside) and its length was about 50 cm. The vertical tubes were made about 5.5 mm. in diameter so as to accommodate the electrodes used in the other experiments. Readings were taken and curves plotted in the same manner as for transverse fields.

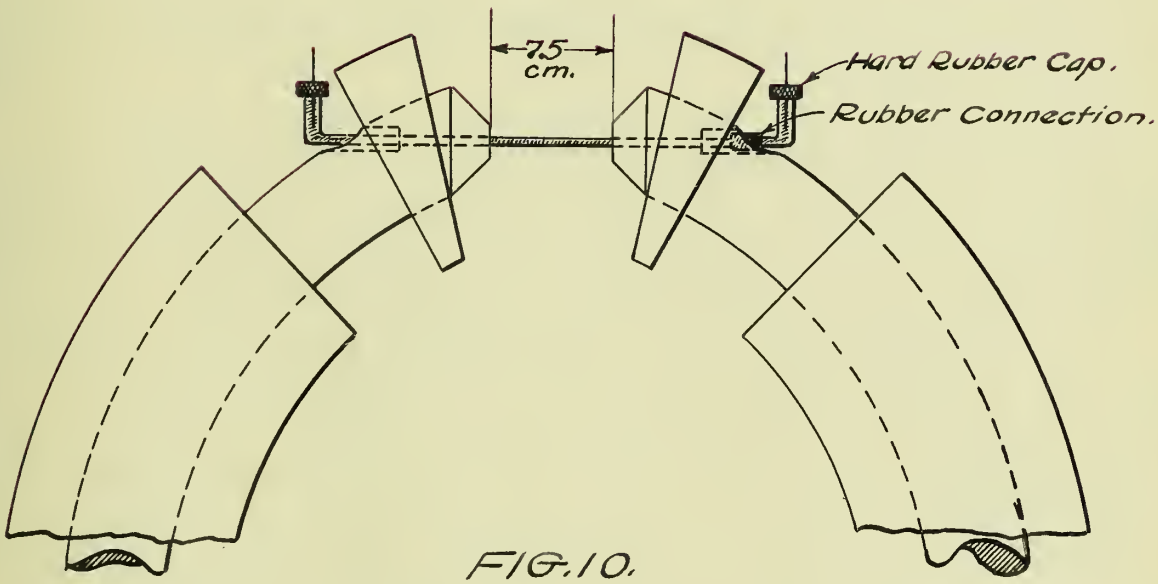


FIG. 10.

Discussion of Results.

All the curves are of the same general type. As a rule the resistance increases at first, due to the polarization of the electrodes. Later the resistance falls off with considerable rapidity. This probably caused by a slight heating due to the large current through the coils of the magnet. Two or three of the curves do not show the initial increase of resistance, but this is because readings were not commenced until after the maximum was passed.

Cobalt chloride shows an average decrease in resistance of 0.19% in curve 4; 0.26% in curve 5; 0.22% in curve 6; and 0.23% in curve 7. The fields used, as in the cases of the other two electrolytes, were about 19,000 lines per square centimeter.

The results for ferric chloride show an average decrease in resistance of 0.29% in curve 8; 0.22% in curve 9; 0.74% in curve 10; and 2.2% in curve 11. Curves 10 and 11 are far less regular than curves 8 and 9, and the results derived from them are much less reliable.

Copper sulphate shows an average increase in resistance of 0.22% in curve 12 and 0.21% in curve 14. It shows an average decrease in resistance of 0.21% in curve 13 and 0.14% in curve 15.

The results for cobalt chloride are the most consistent. It is possible that the decrease in resistance, which was observed in both cobalt chloride and ferric chloride, is due to the action of the field on the ions of the magnetic metals, and is not a true change in resistance. The results for copper sulphate show that the effect observed in it is not a true alteration in resistance

since reversing the direction of the current reverses the sign of the change. Why reversing the direction of the field does not have a similar effect is not clear.

It is possible that all the effects noted were due to the action of the magnetic field on the polarization of the cell at the electrodes, or similar secondary actions. The electrodes were certainly within the field of the magnet though by no means in the strongest part of the field.

If we may apply Thomson's equations to this case, the conclusion that the results obtained were due to a secondary effect of the field, and not to its influence on the specific resistance of the electrolyte, is in accord with the generally accepted views on electrolytic conduction. The expression derived by Thomson for the change in resistance is

$$\frac{\delta\sigma}{\sigma} = \frac{1}{3} H^2 u_o^2$$

where $u_o = \frac{1}{2} \frac{e}{m} T$ See pages 16 and 17. The charge on the electrons is the same as that on the ions. The mass of a cobalt ion is approximately 59,000 times that of an electron; the mass of a copper ion is 63,500 times as great; the mass of an iron ion is 56,000 times the mass of an electron. Hence, unless the time of freedom of the ions is very great, u_o for the ions must be much smaller than u_o for the electrons. This would make the value of $\frac{\delta\sigma}{\sigma}$ very small. It must be remembered that Thomson's theory assumes that conduction takes place by the transfer of electrons in one direction only, while electrolytic conduction takes place by the motion of ions in both directions. Hence it is questionable whether the application of Thomson's equation to electrolytic conduction is valid.

The results for longitudinal fields must be regarded as qualitative since the cell was not in a uniform field. The part of the horizontal tube between the electrodes was in a field of about 3,300 lines per square centimeter, but the other part of the tube was also in a field. This field was much weaker than the one between the pole pieces but no estimate can be formed of its strength.

In all of the electrolytes tested, the sign of the change was reversed upon reversing the direction of the current through the bridge. This shown for copper sulphate in curves 16, 17, 18, and 19; for cobalt chloride in curves 23 and 24; and for ferric chloride in curves 25 and 26. Curves 20, 21, and 22 for copper sulphate seem to contradict this conclusion.

Summary

The sensitiveness attained with the author's apparatus is much higher than that of either of the other investigators who have used a direct current method on electrolytic work. With the least sensitive arrangement, a change of 1 part in 1,000 was easily detected, while in some of the work a change of 1 part in 20,000 could be observed. The transverse magnetic fields used were about 6 times as strong as those used by Berndt, and the longitudinal fields were approximately 3 times as strong as his.

The results show that:-

1. The resistance of a dilute solution of ferric chloride or cobalt chloride is decreased by a strong transverse magnetic field, but it is suspected that this is due to the magnetic

action upon the molecules of the magnetic metal and not to a change in the specific resistance.

2. The resistance of these solutions is affected by a magnetic field parallel to the current, but the effect changes sign when the direction of the current is reversed. It is therefore not a true change in resistance but is due to some secondary effect of the field.

3. The resistance of a dilute solution of copper sulphate is affected by a transverse or a longitudinal magnetic field. In both cases the sign of the change is reversed by reversing the direction of the current. Hence the effect is due to some secondary influence of the field.

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This thesis was prepared during the academic year 1907-08 under the direction of Professor A. P. Carman, Head of the Department of Physics, in the Physical Laboratory of the University of Illinois.

D A T A .

Notation used:-

In calibration of field

R_o - Resistance of bismuth spiral out of field.

R - Resistance of bismuth spiral in field.

I - Magnetizing current.

H - Field as given by bismuth spiral calibration curve.

In observations on electrolytes

T - Time at which reading was taken.

I - Magnetizing current.

H - Field from calibration curve.

R - Calculated resistance of electrolyte.

A - Alteration in resistance produced by field as shown by corresponding curve.

G - Reading of Galvanometer index.

Calibration of Magnetic Field - Solid Pole Pieces - Air Gap 1.12 centimeters.

May 19, 1908.

R	$R - R_o$	$(R - R_o)/R_o$	I	H
25.005			0.0	0.0
27.275	2.27	.0907	1.2	3,300
32.178	7.173	.289	2.6	7,050
39.343	14.338	.5735	5.0	12,300
43.461	18.456	.737	8.0	15,300
45.271	20.266	.81	10.0	16,645
46.662	21.657	.866	12.0	17,665
47.787	22.782	.91	14.0	18,475
48.544	23.539	.94	16.0	19,025
49.148	24.143	.9656	18.0	19,485
49.485	24.48	.979	19.2	19,740

Calibration of Magnetic Field - Bored Pole Pieces - Air Gap 7.5 centimeters.

May 21, 1908.

R	$R - R_o$	$(R - R_o)/R_o$	I	H
24.929			0.0	000
25.366	.431	.0173	4.0	1,050
26.135	1.206	.0482	8.0	2,150
26.532	1.603	.0642	12.0	2,600
26.945	2.016	.087	16.0	3,200
27.207	2.278	.0914	19.3	3,350

Observations on Electrolytes.

Thursday, April 30, 1908.

Cell cleaned and filled with cobalt chloride solution at 8:45 A.M.

Current direct. Circuit closed at 8:58. Galvanometer zero 254.

Ratio arms 11,000 ohms. e.m.f. 39 volts.

T	I	H	G	R	A
9:00:00	0	0	225	315,340	
:00:30	0	0	232	315,740	
:01	0	0	238	316,090	
:01:30	0	0	245	316,540	
:02	0	0	252	316,885	
:02:30	0	0	256	317,110	
:03	0	0	258	317,230	
:03:30	0	0	259	317,285	
:04	0	0	261	317,400	
:04:30	0	0	263	317,515	
:05	0	0	265	317,630	
:05:30	19.18	19,700	260	317,340	350
:06	19.18	19,700	259.5	317,315	375
:06:30	19.18	19,700	261.5	317,430	300
:07	0	0	263.5	317,540	
:07:30	0	0	267	317,740	
:08	0	0	267	317,740	
:08:30	0	0	268	317,800	
:09	0	0	269.5	317,880	
:09:30	0	0	268.5	317,830	
:10	0	0	268	317,800	
:10:30	0	0	267.5	317,700	

T	I	H	G	R	A
9:11	0	0	266.5	317,715	
:11:30	0	0	266	317,685	
:12	0	0	265	317,630	
:12:30	19.4	19,750	257	317,170	-310
:13	19.4	19,750	250	316,770	-550
:13:30	19.4	19,750	247	316,600	-555
:14	0	0	247	316,600	
:14:30	0	0	250	316,770	
:15	0	0	249	316,715	
:15:30	0	0	247	316,600	
:16	0	0	-		
:16:30	0	0	241	316,255	
:17	0	0	238.5	316,115	
:17:30	0	0	237	316,030	
:18	0	0	233	315,800	
:18:30	0	0	229	315,570	
:19	19.0	19 650	218	314,940	-375
:19:30	19.0	19 650	208	314,370	-600
:20	19.0	19 650	198	313,800	-800
:20:30	0	0	194	313,630	
:21	0	0	196.5	313,710	
:21:30	0	0	195	313,630	
:22	0	0	191	313,390	
:22:30	0	0	186	313,110	
:23	0	0	180	312,770	
:23:30	0	0	175	312,490	
:24	0	0	169	312,130	

Current broken at 9:24:30. Reversed at 9:25:30 . Resistance increased from 277,000 at 9:26 to 298,000 at 9:41. Galvanometer zero at 254. 400 ohms increase = 7 mm. decrease in reading.

T	I	H	G	R	A
9:41:30	0	0	246	298,460	
:42	0	0	247	298,400	
:42:30	0	0	248	298,340	
:43	0	0	248	298,340	
:43:30	0	0	248	298,340	
:44	0	0	249	298,285	
:44:30	0	0	250	298,230	
:45	0	0	251	298,170	
:45:30	0	0	252	298,115	
:46	0	0	253	298,060	
:46:30	0	0	253.5	298,030	
:47	18.6	19,570	266	297,315	-550
:47:30	18.6	19,570	274	296,850	-900
:48	18.6	19,570	278	296,630	-1000
:48:30	0	0	278	296,630	
:49	0	0	276	296,740	
:49:30	0	0	274.5	296,820	
:50	0	0	274	296,850	
:50:30	0	0	273	296,920	
:51	0	0	273	296,920	
:51:30	0	0	274	296,850	
:52	0	0	276.5	296,710	
:52:30	0	0	279	296,570	
:53	0	0	281	296,460	

T	I	H	G	R	A
9:53:30	18.4	19,520	290	295,940	-350
:54			296	295,600	-525
:54:30	18.2	19,500	301	295,320	-625
:55	0	0	300.5	295,350	
:55:30	0	0			
:56	0	0	300	295,380	
:56:30	0	0	301.5	295,290	
:57	0	0	305.5	295,060	
:57:30	0	0	307	294,970	
:58	0	0	310	294,800	
:58:30	0	0	312.5	294,660	
:59	0	0	315	294,520	
:59:30	0	0	318	294,340	
10:00	18.2	19,500	327	293,830	-275
:00:30	18.2	19,500	337	293,260	-500
:01	18.2	19,500	346	292,750	-750
:01:30	0	0	348	292,640	
:02	0	0	349	292,580	
:02:30	0	0	351	292,460	
:03	0	0	355	292,250	
:03:30	0	0	358.5	292,040	
:04	0	0	362	291,840	
:04:30	0	0	366	291,600	
:05	0	0	370.5	291,350	
:05:30	0	0	375	291,100	
:06	0	0	380	290,800	

April 30, 1908. P. M. Cobalt Chloride solution. Cell filled and placed in position at 11:45 A. M. e.m.f. 30 volts. Arms 11,000 ohms. Current direct. Circuit closed at 1:37 Balanced at 1:39 with 298,000 ohms. Galvanometer zero 283. 400 ohms increase in resistance equals 6 mm. increase in reading.

T	I	H	G	R	A
1:40	0	0	264.5	296,770	
:40:30	0	0	271	297,200	
:41	0	0	276	297,530	
:41:30	0	0	280.5	297,835	
:42	0	0	289	298,400	
:42:30	0	0	293.5	298,700	
:43	0	0	296	298,865	
:43:30	0	0	298.5	299,030	
:44	0	0	301	299,200	
:44:30	0	0	303	299,330	
:45	0	0,	305	299,465	
:45:30	18.5 dir.	19,550	309	299,730	000
:46	18.6	19,570	305	299,465	-350
:46:30	18.6	19,570	307	299,600	-300
:47	0	0	309	299,730	
:47:30	0	0	310.5	299,830	
:48	0	0	315.5	300,170	
:48:30	0	0	317	300,260	
:49	0	0	316.5	300,230	
:49:30	0	0	312	299,930	
:50	0	0	310	299,800	
:50:30	0	0	309	299,735	

T	I	H	G	R	A
1:51	0	0	303.5	299,370	
:51:30	0	0	312	299,930	
:52	18.6 rev.	19,570	310	299,800	000
:52:30	18.6	19,570	303.5	299,370	-300
:53	18.6	19,570	300	299,130	-350
:53:30	0	0	299	299,065	
:54	0	0	301	299,200	
:54:30	0	0	296	298,865	
:55	0	0	295	298,800	
:55:30	0	0	293.5	298,700	
:56	0	0	291.5	298,565	
:56:30	0	0	289	298,400	
:57	0	0	285.5	298,165	
:57:30	0	0	282.5	297,970	
:58	0	0	297	297,735	
:58:30	18.7 dir.	19,600	273	297,335	-100
:59	18.7	19,600	263	296,670	-550
:59:30	18.7	19,600	258	296,330	-550
2:00	0	0	256.5	296,230	
:00:30	0	0	256.5	296,330	
:01	0	0	254.5	296,100	
:01:30	0	0	252	295,965	
:02	0	0	249.5	295,760	
:02:30	0	0	245.5	295,500	
:03	0	0	241.5	295,240	
:03:30	0	0	237	294,940	
:04	0	0	232.5	294,960	

T	I	H	G	R	A
2:04:30	0	0	227.5	294 300	
:05	21.4 rev.	20,250	218	293,670	-150
:05:30	21.4	20,250	205	292,800	-600
:06	21.4	20,250	197	292,260	-850
:06:30	0	0	192	291,940	
:07	0	0	193.5	292,040	
:07:30	0	0	194	292,060	
:08	0	0	192	291,940	
:08:30	0	0	187	291,600	
:09	0	0	185	291,460	
:09:30	0	0	179.5	291,100	
:10	0	0	172	290,600	
:10:30	0	0	164	290,060	
:11	0	0	157.5	289,640	

Refilled cell with cobalt chloride, cleaned electrodes, and placed cell in position at 3:22 P. M. Galvanometer zero at 285. Arms 11,000 ohms. e.m.f. 30.5 volts. Current reversed. Circuit closed at 4:20 P. M. Balanced at 4:42 with 288,000 ohms. Increase in resistance of 400 ohms = 6 mm. decrease in reading.

4:43:30	0	0	281	288 265	
:44	0	0	276.5	288 565	
:44:30	0	0	272	288 865	
:45	0	0	268	289 130	
:45:30	0	0	264	289 400	
:46	0	0	260	289 470	
:46:30	0	0	256	289 930	

T	I	H	G	R	A
4:47	0	0	251.5	290,230	
:47:30	0	0	247.5	290,500	
:48	0	0	245	290,660	
:48:30	0	0	242.5	290,830	
:49	20.3 dir.	19,950	243	290,800	-200
:49:30	20.3	19,950	241	290,930	-200
:50	20.5	20,000	238.5	291,100	-150
:50:30	0	0	236.5	291,230	
:51	0	0	234	291,400	
:51:30	0	0	233	291,460	
:52	0	0	233	291,460	
:52:30	0	0	233.5	291,430	
:53	0	0	233	291,460	
:53:30	0	0	235	291,330	
:54	0	0	236	291,260	
:54:30	0	0	237.5	291,160	
:55	0	0	239	291,060	
:55:30	20.0 rev.	19,900	242	290,865	- 75
:56	20.0	19,900	249	290,400	-400
:56:30	20.0	19,900	251.5	290,230	-425
:57	0	0	251.5	290,230	
:57:30	0	0	249	290,400	
:58	0	0	250	290,330	
:58:30	0	0	253	290,135	
:59	0	0	256	289,930	
:59:30	0	0	260	289,665	
5:00	0	0	264	289,400	

T	I	H	G	R	A
5:00:30	0	0	267.5	289,165	
:01	0	0	271	288,935	
:01:30	0	0	274	288,730	
:02	20.0 dir.	19,900	283	288,135	-450
:02:30	20.0	19,900	289	287,735	-600
:03	20.0	19,900	298	287,135	-825
:03:30	0	0	303	286,800	
:04	0	0	302	286,865	
:04:30	0	0	301.5	286,900	
:05	0	0	303	286,800	
:05:30	0	0	305.5	286,630	
:06	0	0	310	286,300	
:06:30	0	0	315	286,000	
:07	0	0	320	285,670	
:07:30	0	0	325	285,335	
:08	0	0	330	285,000	
:08:30	19.6 rev.	19,800	345	284,000	- 550
:09	19.6	19,800	357	283,200	- 800
:09:30	19.6	19,800	366	282,600	-1100
:10	0	0	368.5	282,400	
:10:30	0	0	367	282,530	
:11	0	0	369.5	282,370	
:11:30	0	0	374	282,060	
:12	0	0	379.5	281,700	
:12:30	0	0	385.5	281,300	
:13	0	0	391.5	280,900	
:13:30	0	0	397.5	280,500	

T	I	H	G	R	A
5:14	0	0	404	280,070	
:14:30	0	0	410	279,670	

Saturday, May 2, 1908.

Filled cells with ferric chloride and placed in position at 9:40 A.M. Ratio Arms 11,000 ohms. e.m.f. 22.5 volts. Galvanometer zero 278. Current direct. Circuit closed at 10:48. Balancing arm 116,000 ohms. 200 ohms increase = 13 mm.increase.

T	I	H	G	R	A
10:56	0	0	256	117,060	
:56:30	0	0	259	117,110	
:57	0	0	261	117,140	
:57:30	0	0	263.5	117,175	
:58	0	0	265	117,200	
:58:30	0	0	266.5	117,225	
:59	0	0	268	117,245	
:59:30	0	0	269	117,260	
11:00	0	0	270	117,275	
:00:30	0	0	271	117,290	
:01	0	0	273	117,325	
:01:30	19.6	19,800	266	117,215	-300
:02			260	117,125	-500
:02:30	19.4	19,750	258	117,090	-575
:03	19.4	19,750	260	117,125	-550
:03:30	0	0	264	117,185	
:04	0	0	272	117,308	
:04:30	0	0	275.5	117,360	

T	I	H	G	R	A
11:05	0	0	277	117,385	
05:30	0	0	277	117,400	
:06	0	0	277	117,385	
:06:30	0	0	276.5	117,375	
:07	0	0	275	117,355	
:07:30	0	0	273	117,325	
:08	0	0	270.5	117,285	
:08:30	19.6	rev. 19,800	260	117,125	-200
:09	19.4	19,750	248	116,940	-450
:09:30	19.4	19,750	238	116,785	-600
:10	19.2	19,700	233	116,710	-600
:10:30	0	0	230	116,660	
:11	0	0	234	116,720	
:11:30	0	0	232	116,690	
:12	0	0	229	116,645	
:12:30	0	0	225	116,585	
:13	0	0	220	116,505	
:13:30	0	0	214.5	116,420	
:14	0	0	208	116,320	
:14:30	0	0	202	116,230	
:15	0	0	196	116,140	
:15:30	19.1	19,675	177	115,850	- 300
:16	19.1	19,675	153	115,470	- 650
:16:30	19.0	19,650	133	115,185	- 875
:17	18.8	19,600	120	114,985	-1000
:17:30	0	0	115	114,900	
:18	0	0	115	114,900	

T	I	H	G	R	A
11:18:30	0	0	112	114,850	
:19	0	0	107	114,770	
:19:30	0	0	101	114,680	
:20	0	0	93	114,560	
:20:30	0	0	85	114,430	
:21	0	0	75	114,280	

Refilled cell with ferric chloride at 2:40 P. M. Ratio arms 11,000. Galvanometer zero 280. Current reversed. e.m.f. 23 volts. Circuit closed at 6:27 P.M. Resistance increased quite rapidly for some minutes. Balanced at 6:27 with 113,400 ohms. Increase in resistance of 400 ohms equals 26 mm. decrease in reading.

T	I	H	G	R	A
6:29	0	0	277.5	113,450	
:29:30	0	0	273.5	113,495	
:30	0	0	269.5	113,555	
:30:30	0	0	265	113,620	
:31	0	0	261	113,680	
:31:30	0	0	257	113,740	
:32	0	0	253	113,800	
:32:30	0	0	248.5	113,867	
:33	0	0	244.5	113,925	
:33:30	0	0	240.5	113,985	
:34	0	0	236	114,050	
:34:39	20.2	19,920	235	114,065	-100
:35	20.2	19,920	233	114,095	-125
:35:30	20.2	19,920	232	114,110	-160

T	I	H	G	R	A
6:36	20.0 dir.	19,880	233	114,095	-260
:36:30	0	0	229	114,155	
:37	0	0	224	114,230	
:37:30	0	0	220	114,290	
:38	0	0	218	114,320	
:38:30	0	0	217	114,335	
:39	0	0	216.5	114,340	
:39:30	0	0	216.5	114,340	
:40	0	0	217	114,335	
:40:30	0	0	218	114,320	
:41	0	0	219.5	114,295	
:41:30	19.8 rev.	19,850	229	114,155	-200
:42	19.7	19,825	238	114,020	-375
:42:30	19.6	19,800	243	113,958	-400
:43	19.5	19,775	247.5	113,880	-425
:43:30	0	0	250	113,845	
:44	0	0	249.5	113,850	
:44:30	0	0	254	113,785	
:45	0	0	257.5	113,735	
:45:30	0	0	261	113,680	
:46	0	0	265.5	113,615	
:46:30	0	0	271	113,535	
:47	0	0	277	113,445	
:47:30	0	0	283.5	113,350	
:48	0	0	291	113,245	
:48:30	19.6 dir.	19,800	310	112,955	-325
:49	19.4	19,750	333	112,615	-700

T	I	H	G	R	A
6:49:30	19.4 dir.	19,750	350	112,360	-750
:50	19.4	19,750	364	112,155	-750
:50:30	0	0	367	112,110	
:51	0	0	367.5	112,100	
:51:30	0	0	370	112,065	
:52	0	0	374	112,010	
:52:30	0	0	380	111,920	
:53	0	0	388	111,800	
:53:30	0	0	396	111,680	
:54	0	0	405	111,550	
:54:30	0	0	415	111,400	
:55	0	0	426	111,240	

Cleaned electrodes and refilled cell at 7:10 P.M. Current direct. Arms 11,000. e.m.f. 16.5 volts. Circuit closed at 7:45 P. M. Galvanometer zero 280. Balanced at 7:51 with 102,000 ohms. 400 ohms increase in resistance = 24 mm. increase in reading.

T	I	H	G	R	A
7:51	0	0	262	101,700	
:51:30	0	0	270	101,835	
:52	0	0	276	101,935	
:52:30	0	0	281	102,015	
:53	0	0	286	102,100	
:53:30	0	0	291	102,185	
:54	0	0	297	102,285	
:54:30	0	0	303	102,385	
:55	0	0	311	102,515	

T	I	H	G	R	A
7 6:55:30	0	0	321	102,685	
:56	0	0	336.5	102,925	
:56:30	18.1 dir.	19,500	341	103,015	000
:57	15.0	18,700	337	102,950	-160
:57:30	16.2	19,000	338	102,965	-275
:58	15.2	18,800	338	102,965	-400
:58:30	0	0	347	103,140	
:59	0	0	364	103,400	
:59:30	0	0	374	103,565	
8:00	0	0	380	103,665	
:00:30	0	0	386	103,765	
:01	0	0	392	103,870	
:01:30	0	0	398	103,970	
:02	0	0	403	104,050	
:02:30	0	0	407	104,120	
:03	0	0	412	104,200	
:03:30	20.2 rev.	19,900	396	103,930	- 350
:04	20.2	19,900	378	103,635	- 700
:04:30	20.2	19,900	364	103,400	-1000
:05	20.2	19,900	362	103,365	-1100
:05:30	0	0	347	103,140	
:06	0	0	386	103,765	
:06:30	0	0	406	104,100	
:07	0	0	423	104,380	
:07:30	0	0	437	104,620	
:08	0	0	451	104,850	
:08:30	0	0	449	104,820	

T	I	H	G	R	A
8:09	0	0	444	104,730	
:09:30	0	0	440	104,660	
:10	0	0	436.5	104,600	
:10:30	19.8 dir.	19,850	426	104,430	-160
:11	19.6	19,800	411	104,180	-400
:11:30	19.6	19,800	407	104,120	-400
:12	19.2	19,700	409	104,150	-350
:12:30	0	0	397	103,950	
:13	0	0	415	104,250	
:13:30	0	0	418	104,300	
:14	0	0	418	104,300	
:14:30	0	0	417	104,280	
:15	0	0	414	104,230	
:15:30	0	0	411	104,180	
:16	0	0	407.5	104,125	
:16:30	0	0	403	104,050	
:17	0	0	398	103,970	
:17:30	19.2 rev.	19,700	382	103,700	-150
:18	19.1	19,675	364	103,400	-400
:18:30	19.1	19,675	350	103,165	-500
:19	19.1	19,675	340	103,000	-500
:19:30	0	0	324	102,735	
:20	0	0	354	103,235	
:20:30	0	0			
:21	0	0	351	103,185	
:21:30	0	0	347	103,140	
:22	0	0	342	103,035	

T	I	H	G	R	A
8:22:30	0	0	335	102,915	
:23	0	0	329	102,815	
:23:30	0	0	322	102,700	

Refilled cell at 8:32 P. M. Ratio Arms 11,000 ohms. e.m.f. 16.5 volts. Galvanometer zero 250. Current reversed. Circuit closed at 9:04 P.M. Balanced at 9:10:30 with 93,000 ohms. 400 ohms increase in resistance = 28 mm. decrease in reading.

T	I	H	G	R	A
9:10:30	0	0	284	92,515	
:11	0	0	272	92,685	
:11:30	0	0	263	92,815	
:12	0	0	257	92,900	
:12:30	0	0	252.5	92,965	
:13	0	0	246	93,055	
:13:30	0	0	240	93,140	
:14	0	0	233.5	93,235	
:14:30	0	0	226.5	93,335	
:15	0	0	219.5	93,450	
:15:30	0	0	209	93,585	
:16	19.6 dir.	19,800	210	93,570	- 100
:16:30	19.6	19,800	230	93,285	- 300
:17	19.6	19,800	251	92,985	- 800
:17:30	19.5	19,775	278	92,600	-1300
:18	0	0	285	92,500	
:18:30	0	0	230	93,285	
:19	0	0	218	93,465	
:19:30	0	0	210	93,570	

T	I	H	G	R	A
9:20	0	0	199	93,730	
:20:30	0	0	186	93,915	
:21	0	0	167	94,185	
:21:30	0	0	151	94,415	
:22	0	0	143	94,530	
:22:30	0	0	136	94,630	
:23	19.1 rev.	19,675	129	94,725	000
:23:30	19.1	19,675	120	94,855	000
:24	18.9	19,625	121	94,840	-100
:24:30	18.9	19,625	116	94,915	-100
:25	0	0	115	94,930	
:25:30	0	0	100	95,140	
:26	0	0	99	95,155	
:26:30	0	0	100	95,140	
:27	0	0	100	95,140	
:27:30	0	0	99	95,155	
:28	0	0	97	95,180	
:28:30	0	0	93.5	95,240	
:29	0	0	90	95,340	
:29:30	0	0	86	95,340	
:30	19.0 dir.	19,650	109	95,015	- 350
:30:30			145	94,500	- 850
:31			163	94,240	-1125
:31:30	18.8	19,600	163	94,240	-1125
:32	0	0	155	94,355	
:32:30	0	0	143	94,530	
:33	0	0	130	94,715	

T	I	H	G	R	A
9:33:30	0	0	115	94,930	
:34	0	0	99	95,155	
:34:30	0	0	96	95,200	
:35	0	0	95	95,215	
:35:30	0	0	93.5	95,235	
:36	0	0	93	95,240	
:36:30	0	0	93	95,240	
:37	19.0 rev.	19,650	101	95,125	- 75
:37:30	18.6	19,570	305	92,285	-2875
:38	18.6	19,570	338	91,740	-3450
:38:30	18.6	19,570	275	92,640	-2250
:39	0	0	212	93,545	
:39:30	0	0	144	94,510	
:40	0	0	136	94,630	
:40:30	0	0	137	94,615	
:41	0	0	140	94,570	
:41:30	0	0	143	94,530	
:42	0	0	147	94,470	
:42:30	0	0	152	94,400	
:43	0	0	157	94,330	
:43:30	0	0	163	94,240	

May 14, 1908.

Cell cleaned and filled with copper sulphate solution preceeding evening. Ratio Arms 11,000 ohms e.m.f. 37 volts. Galvanometer zero 270. Current direct. Circuit closed at 7:42 A.M. Balanced at 7:55 with 565,000 ohms. Increase of 400 ohms = 2 mm. increase in reading.

T	I	H	G	R	A
7:55	0	0	249.5	560,900	
:55:30	0	0	249.5	560,900	
:56	0	0	249.5	560,900	
:56:30	0	0	249.5	560,900	
:57	0	0	249.5	560,900	
:57:30	0	0	249.5	560,900	
:58	0	0	249.5	560,900	
:58:30	0	0	249.7	560,940	
:59	0	0	249.7	560,940	
:59:30	0	0	250	561,000	
8:00	0	0	250	561,000	
:00:30	20.6 dir.	20,000	255	562,000	+ 1000
:01	20.4	19,975	254.5	561,900	900
:01:30	20.2	19,950	254	561,800	900
:02	20.2	19,950	254	561,8000	900
:02:30	0	0	249	560,800	
:03	0	0	248.3	560,660	
:03:30	0	0	247.5	560,500	
:04	0	0	244	559,800	
:04:30	0	0	245.5	560,100	
:05	0	0	244.5	559,900	
:05:30	0	0	243	559,600	
:06	0	0	242	559,400	
:06:30	0	0	240	559,000	
:07	0	0	238.3	558,660	
:07:30	20.2 rev.	19,950	240.5	559,100	+ 1300
:08	20.1	19,925	235	558,000	1300

T	I		H	G	R	A
8:08:30	20.0	rev.	19,900	232	557,400	1300
:09	19.9		19,875	228.5	556,500	1300
:09:30	0		0	218	554,600	
:10	0		0	215.5	554,100	
:10:30	0		0	213	553,600	
:11	0		0	211.5	553,300	
:11:30	0		0	209.5	552,800	
:12	0		0	207	552,400	
:12:30	0		0	204	551,800	
:13	0		0	201	551,200	
:13:30	0		0	198	550,600	
:14	0		0	194.5	549,900	
:14:30	20.2	dir.	19,950	195	550,000	1600
:15	20.0		19,900	194	549,800	2500
:15:30	19.8		19,850	179	546,800	1200
:16	19.6		19,800	173	545,600	1200
:16:30	0		0	159	542,800	
:17	0		0	156	542,200	
:17:30	0		0	153.5	541,700	
:18	0		0	150	541,000	
:18:30	0		0	148	540,600	
:19	0		0	145	540,000	
:19:30	0		0	140.5	539,100	
:20	0		0	136	538,200	
:20:30	0		0	130	537,000	
:21	0		0	125	556,000	

Cell refilled with copper sulphate solution and placed in position at 8:34 A. M. Ratio arms 11,000 ohms. e.m.f. 37 volts. Galvanometer zero 270. Current reversed. Circuit closed at 10:15 A.M. Balanced at 10:18 with 527,000 ohms. 400 ohms increase in resistance = 2 mm. decrease in readings.

T	I	H	G	R	A
10:19:30	0	0	266	527,800	
:20	0	0	266	527,800	
:20:30	0	0	265	528,000	
:21	0	0	265	528,000	
:21:30	0	0	264.5	528,100	
:22	0	0	264.3	528,140	
:22:30	0	0	264	528,200	
:23	0	0	263.5	528,300	
:23:30	0	0	263	528,400	
:24	0	0	263	528,400	
:24:30	0	0	264	528,300	
:25	0	0	263	528,400	
:25:30	18.6 dir.	19,600	268	527,200	- 1200
:26	18.5	19,570	268	527,200	- 1200
:26:30	18.4	19,540	268	527,200	- 1100
:27	18.4	19,590	268	527,200	- 1100
:27:30	0	0	265	528,000	
:28	0	0	264.5	528,100	
:28:30	0	0	265	528,000	
:29	0	0	265.5	527,900	
:29:30	0	0	266	527,300	
:30	0	0	267	527,600	

T	I	H	G	R	A
10:30:30	0	0	268	527,400	
:31	0	0	268	527,400	
:31:30	0	0	270	527,000	
:32	0	0	271	526,800	
:32:30	18.4 rev.	19,540	277	525,600	- 850
:33	18.3	19,525	280	525,000	- 1100
:33:30	18.2	19,510	282	524,600	- 1100
:34	18.1	19,500	284	524,200	- 1000
:34:30	0	0	282	524,600	
:35	0	0	283	524,400	
:35:30	0	0	285	524,000	
:36	0	0	286.5	524,000	
:36:30	0	0	288	523,400	
:37	0	0	290	523,000	
:37:30	0	0	292.5	522,500	
:38	0	0	295	522,000	
:38:30	0	0	297.5	521,500	
:39	0	0	300	521,000	
:39:30	18.2 dir.	19,510	309	519,200	- 1000
:40	18.1	19,500	316	517,800	- 1500
:40:30	18.0	19,480	321.5	516,700	- 1500
:41	17.9	19,450	326.5	515,700	- 1500
:41:30	0	0	326	515,800	
:42	0	0	328	515,400	
:42:30	0	0	331	514,800	
:43	0	0	334	514,200	
:43:30	0	0	337	513,600	

T	I	H	G	R	A
10:44	0	0	340	513,000	
:44:30	0	0	344	512,200	
:45	0	0	348	511,400	
:45:30	0	0	352	510,600	
:46	0	0	356	509,800	

Filled mate to cell previously used with copper sulphate solution and placed it in position at 2:00 P. M. Ratio Arms 11,000 ohms. e.m.f. 37 volts. Galvanometer zero 260. Current direct. Circuit closed at 4:25 P.M. Balanced at 4:28 with 555,000 ohms. Increase of 400 ohms equals 2 mm. increase in resistance.

T	I	H	G	R	A
4:29	0	0	261	555,200	
:29:30	0	0	261	555,200	
:30	0	0	261	555,200	
:30:30	0	0	260.5	555,100	
:31	0	0	260	555,000	
:31:30	0	0	259.5	554,900	
:32	0	0	259.5	554,900	
:32:30	0	0	259	554,800	
:33	0	0	259	554,800	
:33:30	0	0	259	554,800	
:34	0	0	258.5	554,700	
:34:30	19.2 dir.	19,740	264	555,800	+1100
:35	19.0	19,700	264	555,800	+1100
:35:30	19.0	19,700	264	555,800	+1100
:36	19.0	19,700	264	555,800	+1200
:36:30	0	0	259	554,800	

T	I	H	G	R	A
4:37	0	0	258	554,600	
:37:30	0	0	257.5	554,500	
:38	0	0	257	554,400	
:38:30	0	0	256.5	554,300	
:39	0	0	255.5	554,100	
:39:30	0	0	254	553,800	
:40	0	0	253.5	553,700	
:40:30	0	0	252.5	553,500	
:41	0	0	251	553,200	
:41:30	18.8 dir.	19,650	255.5	554,100	+1150
:42	18.8	19,650	253	553,600	+1100
:42:30	18.8	19,650	251	553,200	+1100
:43	18.7	19,625	248.5	552,700	+1000
:43:30	0	0	241.5	551,300	
:44	0	0	239.5	550,900	
:44:30	0	0	236	550,200	
:45	0	0	234	549,800	
:45:30	0	0	232	549,400	
:46	0	0	229	548,800	
:46:30	0	0	227	548,400	
:47	0	0	224	547,800	
:47:30	0	0	222	547,400	
:48	0	0	219.5	546,900	
:48:30	19.3 rev.	19,760	223	547,600	+1600
:49	19.2	19,740	217	546,400	+1200
:49:30	19.2	19,740	213	545,600	+1100
:50	19.1	19,700	209	544,300	+1100

T	I	H	G	R	A
4:50:30	0	0	199.5	542,900	
:51	0	0	196	542,200	
:51:30	0	0	193	541,600	
:52	0	0	190	541,000	
:52:30	0	0	186.5	540,300	
:53	0	0	182.5	539,500	
:53:30	0	0	178.5	538,700	
:54	0	0	174.5	537,900	
:54:30	0	0	170	537,000	
:55	0	0	166	536,200	

Refilled cell and placed in position at 5:07 P.M. Galvanometer zero 270. Ratio arms 11,000 ohms. e.m.f. 37 volts. Current reversed. Circuit closed at 7:21 P.M. Balanced at 7:22 with 535,000 ohms. 400 ohms increase = 2 mm. decrease in reading.

T	I	H	G	R	A
7:23	0	0	268	535,400	
:23:30	0	0	267.5	535,500	
:24	0	0	267	535,600	
:24:30	0	0	266.5	535,700	
:25	0	0	266.5	535,700	
:25:30	0	0	266	535,800	
:26	0	0	266	535,800	
:26:30	0	0	266	535,800	
:27	0	0	266	525,800	
:27:30	0	0	266	525,800	
:28	0	0	266	525,800	
:28:30	19.8 dir.	19,850	270	535,000	- 850

T	I	H	G	R	A
7:29			270	535,000	- 800
:29:30			269.5	535,100	- 700
:30	19.4	19,770	269	535,200	- 600
:30:30	0	0	266.5	535,700	
:31	0	0	266.5	535,700	
:31:30	0	0	266.5	535,700	
:32	0	0	266.5	535,700	
:32:30	0	0	267	535,600	
:33	19.2 rev.	19,740	271	534,800	- 600
:33:30	19.0	19,700	272	534,600	- 500
:34	0	0	271	534,800	
:34:30	0	0	272	534,600	
:35	0	0	273	534,400	
:35:30	0	0	274	534,200	
:36	0	0	276	533,800	
:36:30	0	0	278	533,400	
:37	0	0	279.5	533,100	
:37:30	0	0	281.5	532,700	
:38	0	0	283	532,400	
:38:30	0	0	285	532,000	
:39	19.6 rev.	19,800	290	531,000	- 600
:39:30	19.6	19,800	294	530,200	- 600
:40	0	0	295	530,000	
:40:30	0	0	297	529,600	
:41	0	0	299	529,200	
:41:30	19.4 dir.	19,770	305	528,000	- 600
:42	19.4	19,770	309	527,200	- 600

T	I	H	G	R	A
7:42:30	19.4 dir.	19,770	315	526,000	- 1100
:43	19.4	19,770	318.5	525,700	- 1000
:43:30	0	0	319	525,200	
:44	0	0	322	524,600	
:44:30	0	0	324	524,200	
:45	0	0	327	523,600	
:45:30	0	0	330	523,000	
:46	0	0	334	522,200	
:46:30	0	0	338	521,400	
:47	0	0	343	520,400	
:47:30	0	0	347	519,600	
:48	0	0	350.5	518,900	

May 19, 1908.

Cell had been filled and placed in position for several days. Copper sulphate solution. Galvanometer zero 280. Ratio arms 11,000 ohms. e.m.f. 37 volts. Current direct. Circuit closed at 8:59 A.M. Balanced at 9:00 with 568,000 ohms. Increase in resistance of 400 ohms = 2 mm. decrease in reading.

T	I	H	G	R	A
9:02	0	0	281.5	568,300	
:02:30	0	0	282	568,400	
:03	0	0	282.5	568,500	
:03:30	0	0	283	568,600	
:04	0	0	283.4	568,680	
:04:30	0	0	283.8	568,760	
:05	0	0	284.2	568,840	
:05:30	0	0	284.6	568,920	

T	I	H	G	R	A
9:06	0	0	285	569,000	
:06:30	0	0	285.4	569,100	
:07	0	0	286	569,200	
:07:30	17.2 dir.	19,275	289	569,800	+700
:08	17.0	19,200	289	569,800	+650
:08:30			288.3	569,660	+500
:09	17.6	19,350	288	569,600	+400
:09:30	0	0	286	569,200	
:10	0	0	286	569,200	
:10:30	0	0	286	569,200	
:11	0	0	285.3	569,060	
:11:30	0	0	285	569,000	
:12	0	0	284.5	568,900	
:12:30	0	0	284	568,800	
:13	0	0	283.5	568,700	
:13:30	0	0	282.5	568,500	
:14	0	0	281.5	568,300	
:14:30	17.4 rev.	19,300	284	568,800	+900
:15	17.4	19,300	282	568,400	+800
:15:30	17.2	19,260	279	567,800	+400
:16	17.2	19,260	277	567,400	+300
:16:30	0	0	273	566,600	
:17	0	0	271.5	566,300	
:17:30	0	0	270	566,000	
:18	0	0	268.5	565,700	
:18:30	0	0	267	565,400	
:19	0	0	265	565,000	

T	I	H	G	R	A
9:19:30	0	0	263	564,600	
:20	0	0	261	564,200	
:20:30	0	0	259	563,800	
:21	0	0	257	563,400	
:21:30	17.6 dir.	19,360	257	563,400	+700
:22	17.5	19,320	254	562,800	+700
:22:30	17.2	19,260	250	562,000	+600
:23	17.0	19,200	247	561,400	+600
:23:30	0	0	241	560,200	
:24	0	0	239	559,800	
:24:30	0	0	236.5	559,300	
:25	0	0	234	558,800	
:25:30	0	0	231.5	558,300	
:26	0	0	229	557,900	
:26:30	0	0	225.5	557,100	
:27	0	0	222.5	556,500	
:27:30	0	0	220	556,000	
:28	0	0	218	555,600	

Same solution as before. Cleaned electrodes and replaced in cell. Current reversed. Galvanometer zero 280. Ratio arms 11,000 ohms e.m.f. 37 volts. Circuit closed at 9:35:30 A.M. Balanced with 547,000 ohms at 9:36. 400 ohms increase = 2 mm. decrease in readings.

T	I	H	G	R	A
9:37:30	0	0	293	544,400	
:38	0	0	295	544,000	
:38:30	0	0	298	543,400	

T	I	H	G	R	A
9:39	0	0	300	543,000	
:39:30	0	0	302.5	542,500	
:40	0	0	305	542,000	
:40:30	0	0	307.5	541,500	
:41	0	0	310	541,000	
:41:30	0	0	312.5	540,500	
:42	0	0	315	540,000	
:42:30	0	0	317	539,600	
:43	16.8 dir.	19,200	324	538,200	- 800
:43:30	16.8	19,200	328	537,400	- 800
:44	16.4	19,100	332	536,600	- 900
:44:30	16.2	19,060	336	535,800	-1000
:45	0	0	336	535,800	
:45:30	0	0	337.5	535,500	
:46	0	0	339	535,200	
:46:30	0	0	341	534,800	
:47	0	0	343	534,400	
:47:30	0	0	345	534,000	
:48	0	0	347.5	533,500	
:48:30	0	0	350	533,000	
:49	0	0	352.5	532,500	
:49:30	0	0	354.5	532,100	
:50	16.4 rev.	19,100	361.5	530,700	- 700
:50:30			366	529,800	- 700
:51			370	529,000	- 800
:51:30	16.0	19,025	374.5	528,100	- 850
:52	0	0	374	528,200	

T	I	H	G	R	A
9:52:30	0	0	376.5	527,700	
:53	0	0	379	527,200	
:53:30	0	0	382	526,600	
:54	0	0	384.5	526,100	
:54:30	0	0	387.5	525,500	
:55	0	0	390.5	524,900	
:55:30	0	0	394	524,300	
:56	0	0	397	523,600	
:56:30	0	0	401	522,800	

May 21, 1908.

Long cell filled with copper sulphate solution placed in position with bored pole-pieces. e.m.f. 33 volts. Current direct. Circuit closed at 2:27:30 P.M. Galvanometer zero 300. Balanced with 416,000 ohms at 2:30:30. Ratio arms 11,000 ohms. 400 ohms increase = 3 mm. increase.

T	I	H	G	R	A
2:30:30	0	0	296	415,465	
:31	0	0	300	416,000	
:31:30	0	0	302	416,265	
:32	0	0	302.5	416,335	
:32:30	0	0	304	416,535	
:33	0	0	307	416,935	
:33:30	0	0	307	416,935	
:34	0	0	307.5	417,000	
:34:30	0	0	311	417,470	
:35	0	0	313	417,735	
:35:30	0	0	314	417,865	
:36	19 dir.	3,330	395	428,670	+ ?
:36:30	19	3,330	429	433,200	+ 3000
:37	19	3,330	434	433,880	+ 3500
:37:30	19	3,330	435	434,000	+ 3500
:38	0		422	432,300	
:38:30	0		415	431,330	
:39	0		414	431,200	
:39:30	0		413	431,070	
:40	0		412	430,940	
:40:30	0	0	409	430,520	

T	I	H	G	R	A
2:41	0	0	408	430,400	
:41:30	0	0	406.5	430,200	
:42	0	0	405	430,000	
:42:30	0	0	403	429,710	
:43	19.4 rev.	3,350	418	431,700	+ 2200
:43:30			418	431,700	+ 2450
:44	19.3 rev.	3,350	416	431,450	+ 2550
:44:30	19.2 "	3,345	413	431,050	+ 2550
:45	0	0	396	428,800	
:45:30	0	0	391	428,135	
:46	0	0	387	427,600	
:46:30	0	0	384.5	427,265	
:47	0	0	381	426,800	
:47:30	0	0	377	426,265	
:48	0	0	374	425,865	
:48:30	0	0	370	425,330	
:49	0	0	368	425,070	
:49:30	0	0	366	424,800	
:50	19.2 dir.	3,345	378	426,400	+ 2000
:50:30			376.5	426,200	+ 2000
:51	19	3,330	373	425,750	+ 2000
:51:30		3,330	369	425,200	+ 2000
:52	0	0	352	422,930	
:52:30	0	0	349	422,530	
:53	0	0	345	422,000	
:53:30	0	0	340	421,335	
:54	0	0	335	420,665	
:54:30	0	0	328	419,735	

T	I	H	G	R	A
2:55	0	0	325.5	419,400	
:55:30	0	0	322	418,935	
:56	0	0	318	418,400	
:56:30	0	0	313	417,735	
:57	19 rev.	3330	326.5	419,540	+ 2200
:57:30		3330	323.5	419,135	+ 2200
:58		3330	322	418,935	+ 2500
:58:30		3330	315	418,000	+ 2150
:59	0	0	296	415,465	
:59:30	0	0	297.5	415,135	
3:00:00	0	0	290	414,665	
:00:30	0	0	284	413,865	
:01	0	0	277	412,935	
:01:30	0	0	272	412,265	
:02	0	0	266	411,465	
:02:30	0	0	263	411,065	
:03	0	0	259	410,535	
:03:30	0	0	255	410,000	

Same solution. Electrodes cleaned and current reversed. Galvanometer zero 300. 400 ohms increase = 5 mm. decrease. Balance = 415,000.

T	I	H	G	R	A
3:16	0	0	303	414,600	
:16:30	0	0	305	414,735	
:17	0	0	307	414,070	
:17:30	0	0	309	413,800	
:18	0	0	311.5	413,470	

T	I	H	G	R	A
3:18:30	0	0	312.5	413,335	
:19	0	0	313	413,270	
:19:30	0	0	314.5	413,070	
:20	0	0	314	413,135	
:20:30	0	0	314.5	413,070	
:21	0	0	315.5	412,965	
:21:30	19.2 dir.	3345	327	411,400	- 1625
:22	19.2 "	3345	326	411,535	- 1500
:22:30	19.2 "	3345	324	411,800	- 1200
:23	19.2 "	3345	324	411,800	- 1150
:23:30	0	0	314	413,135	
:24	0	0	315	413,000	
:24:30	0	0	317	412,735	
:25	0	0	319	412,465	
:25:30	0	0	321	412,200	
:26	0	0	324.5	411,735	
:26:30	0	0	326.5	411,465	
:27	0	0	328	411,265	
:27:30	0	0	332	410,735	

May 22, 1908.

Long cell filled with copper sulphate at 2 P.M. e.m.f. = 37 volts. Current reversed. Galvanometer zero 250. Circuit closed at 2:13:30. Balanced at 2:15 with 492,000 ohms. Ratio arms 11,000. 1000 ohms increase = 5 mm. decrease.

T	I	H	G	R	A
2:16	0	0	247	492,600	
:16:30	0	0	245.5	492,900	
:17	0	0	244.5	493,100	
:17:30	0	0	244	493,200	
:18	0	0	243.5	493,300	
:18:30	0	0	243.5	493,300	
:19	0	0	243	493,400	
:19:30	0	0	243	493,400	
:20	0	0	242	493,600	
:20:30	0	0	241.5	493,700	
:21	0	0	241	493,800	
:21:30	20.4 dir.	3400	240	494,000	+ 200
:22	20 "	3380	245	493,000	- 1000
:22:30		3380	244	493,200	- 800
:23	19.9 "	3370	242	493,600	- 500
:23:30	0	0	238	494,400	
:24	0	0	240	494,000	
:24:30	0	0	242.5	493,500	
:25	0	0	247	493,400	
:25:30	0	0	244	493,200	
:26	0	0	245.5	492,900	
:26:30	0	0	247	492,600	
:27	0	0	248	492,400	
:27:30	0	0	250	492,000	
:28	0	0	252	491,600	
:28:30	19.8 dir.	3370	255	491,000	0
:29	19.6 "	3360	260	490,000	- 600

T	I	H	G	R	A
2:29:30	19.4 dir.	3350	263	489,400	- 700
:30	19.2 "	3345	266	488,800	- 700
:30:30	0	0	264	489,200	
:31	0	0	267	488,600	
:31:30	0	0	271	487,800	
:32	0	0	272.5	487,500	
:32:30	0	0	275	487,000	
:33	0	0	276.5	486,700	
:33:30	0	0	280	486,000	
:34	0	0	282	485,600	
:34:30	0	0	285	485,000	
:35	0	0	288	484,400	
:35:30	18.8 rev.	3320	295	483,000	- 700
:36	18.8 "	3320	298.5	482,300	- 1000
:36:30		3320	305	481,000	- 1400
:37		3320	308	480,400	- 1200
:37:30	0	0	306	480,800	
:38	0	0	310	480,000	
:38:30	0	0	314.5	479,100	
:39	0	0	318	478,400	
:39:30	0	0	321	477,800	
:40	0	0	325	477,000	
:40:30	0	0	330	476,000	
:41	0	0	334	475,200	
:41:30	0	0	338	474,400	
:42	0	0	342	473,600	

Cell refilled. Current direct. Galvanometer zero 250.

Circuit closed at 2:51 P.M. Balanced at 2:52 with 428,000 ohms.

2000 increase = 12.5 mm increase.

T	I	H	G	R	A
2:53	0	0	247	427,520	
:53:30	0	0	245	427,200	
:54	0	0	244	427,040	
:54:30	0	0	243	426,880	
:55	0	0	241.5	426,640	
:55:30	0	0	240	426,400	
:56	0	0	238	426,080	
:56:30	0	0	236	425,760	
:57	0	0	234.5	425,520	
:57:30	0	0	234	425,440	
:58	0	0	232	425,120	
:58:30	18.4 rev.	3310	195	419,200	- 4400
:59			204	420,650	- 3700
:59:30			210	421,600	- 2400
3:00	18.4 "	3300	204	420,650	- 3000
:00:30	0	0	220	423,200	
:01	0	0	217.5	422,800	
:01:30	0	0	215	422,400	
:02	0	0	212	421,920	
:02:30	0	0	208	421,280	
:03	0	0	203	420,480	
:03:30	0	0	200	420,000	
:04	0	0	197	419,520	
:04:30	0	0	194	419,040	

T	I	H	G	R	A
3:05	0	0	191	418,600	
:05:30	18.6 dir.	3310	170	415,200	- 3000
:06			162	413,900	- 3700
:06:30			158	413,300	- 3700
:07	18.2 "	3290	159	413,440	- 3300
:07:30	0	0	179	416,650	
:08	0	0	176	416,160	
:08:30	0	0	172	415,520	
:09	0	0	169.5	415,120	
:09:30	0	0	166	414,560	
:10	0	0	162.5	414,000	
:10:30	0	0	159	413,440	
:11	0	0	156	412,960	
:11:30	0	0	152.5	412,400	
:12	0	0	150	412,000	

Same solution. Electrodes cleaned and current reversed. Galvanometer zero 250. Balanced at 3:18 P.M. with 429,000 ohms. 2000ohms increase = 13 mm. decrease in reading.

T	I	H	G	R	A
3:18:30	0	0	250	429,000	
:19	0	0	252	428,690	
:19:30	0	0	253	428,540	
:20	0	0	253	428,540	
:20:30	0	0	254	428,785	
:21	0	0	257	427,920	
:21:30	0	0	256	428,075	
:22	0	0	255	428,230	

T	I	H	G	R	A
3:22:30	0	0	256	428,075	
:23	0	0	258	427,770	
:23:30	0	0	258	427,770	
:24	20 dir.	3380	266	426,540	- 1050
:24:30			266	426,540	- 850
:25			266	426,540	- 650
:25:30	19.6 "	3360	264	426,840	- 200
:26	0	0	262	427,150	
:26:30	0	0	270	425,920	
:27	0	0	270	425,920	
:27:30	0	0	270	425,920	
:28	0	0	271	425,760	
:28:30	0	0	274	425,300	
:29	0	0	276	425,000	
:29:30	0	0	281	424,230	
:30	0	0	283	423,920	

May 23, 1908.

Cell filled with cobalt chloride the preceding evening; other conditions as above. Galvanometer zero 250. e.m.f. 33 volts. Current direct. Circuit closed at 10:05 A.M. Balanced at 10:10 with 258,000. 1000 ohms increase = 16.5 mm. increase.

T	I	H	G	R	A
10:10	0	0	247	257,575	
:10:30	0	0	245.5	257,730	
:11	0	0	249	257,940	
:11:30	0	0	248	257,880	

T	I	H	G	R	A
10:12	0	0	250.5	258,070	
:12:30	0	0	254	258,240	
:15	0	0	256.5	258,395	
:17:30	0	0	259	258,545	
:14	0	0	261	258,670	
:14:30	0	0	264	258,850	
:15	0	0	266.5	259,000	
:15:30	19.2 dir.	3345	274.5	259,490	+ 450
:16	19 "	3330	275.5	259,550	+ 475
:16:30	18.9 "	3325	276	259,580	+ 475
:17	18.8 "	3320	276	259,580	+ 450
:17:30	0	0	268.5	259,120	
:18	0	0	267.5	259,060	
:18:30	0	0	266	259,000	
:19	0	0	263.5	258,820	
:19:30	0	0	262	258,730	
:20	0	0	260	258,610	
:20;30	0	0	257	258,425	
:21	0	0	255	258,300	
:21:30	0	0	252.5	258,150	
:22	0	0	250	258,000	
:22:30	18.8 rev.	3320	255	258,700	+ 500
:23		3320	251	258,060	+ 500
:23:30		3320	247	257,820	+ 500
:24	18.4 "	3300	243	257,575	+ 450
:24:30	0	0	231	256,850	
:25	0	0	226	256,550	

T	I	H	G	R	A
10:25:30	0	0	220	256,120	
:26	0	0	215	256,760	
:26:30	0	0	205	255,270	
:27	0	0	199	254,900	
:27:30	0	0	194	254,600	
:28	0	0	187.5	254,200	
:28:30	0	0	180	253,780	
:29	0	0	174	253,390	

Cell refilled. Electrodes and current reversed. Galvanometer zero 250. Circuit closed at 10:45 A.M. Balanced at 10:47 with 242,000 ohms. 1000 ohms increase = 20 mm. decrease.

T	I	H	G	R	A
10:47	0	0	250	242,000	
:47:30	0	0	247	242,150	
:48	0	0	245	242,255	
:48:30	0	0	244	242,700	
:49	0	0	244	242,300	
:49:30	0	0	245.5	242,275	
:50	0	0	246	242,200	
:50:30	0	0	247	242,150	
:51	0	0	248	242,100	
:51:30	0	0	250	242,000	
:52	0	0	251	241,950	
:52:30	18.2 dir.	3290	258	241,900	0
:53		3290	260.5	241,475	- 300
:53:30		3290	267	241,750	- 350

T	I	H	G	R	A
10:54	18.2 dir.	3290	267	241,150	- 350
:54:30	0	0	267	241,350	
:55	0	0	264	241,300	
:55:30	0	0	267	241,150	
:56	0	0	270	241,000	
:56:30	0	0	273	240,850	
:57	0	0	277	240,650	
:57:30	0	0	280.5	240,475	
:58	0	0	285	240,250	
:58:30	0	0	287	240,150	
:59	0	0	290	240,000	
:59:30	0	0	293	239,875	
11:00	18 rev.	3275	303	239,350	- 300
:00:30			307	239,150	- 250
:01			310	239,000	- 200
:01:30	17.8 "	3260	315	238,750	- 250
:02	0	0	313	238,850	
:02:30	0	0	318	238,600	
:03	0	0			
:03:30	0	0	323	238,350	
:04	0	0	329	238,050	
:04:30	0	0	334	237,800	
:05	0	0	340	237,500	
:05:30	0	0	345	237,250	
:06	0	0	349	237,050	
:06:30	0	0	355	236,750	

Cell filled with ferric chloride solution about 11:30 A.M. Ratio arms 11,000 ohms. e.m.f. 22.5 volts. Galvanometer zero 250. Current direct. Circuit closed at 1:30:30 P.M. Balance at 1:33:30 with 86,200 ohms. Increase in resistance of 400 ohms equals 40 mm. increase.

T	I	H	G	R	A
1:33:30	0	0	249	86,190	
:34	0	0	257	86,270	
:34:30	0	0	261	86,310	
:35	0	0	263	86,330	
:35:30	0	0	266	86,360	
:36	0	0	269	86,390	
:36:30	0	0	271	86,410	
:37	0	0	273	86,430	
:37:30	0	0	275.5	86,455	
:38	0	0	277.5	86,475	
:38:30	0	0	279	86,490	
:39	19.7 dir.	3,370	291	86,710	+215
:39:30	19.6	3,365	293.5	86,755	240
:40	19.5	3,360	293	86,730	240
:40:30	19.4	3,355	293	86,730	240
:41	0	0	274	86,440	
:41:30	0	0	271	86,410	
:42	0	0	275	86,450	
:42:30	0	0	272	86,420	
:43	0	0	268.5	86,385	
:43:30	0	0	264.5	86,345	
:44	0	0	260	86,300	

T	I	H	G	R	A
1:44:30	0	0	253.5	86,235	
:45	0	0	247	86,170	
:45:30	0	0	241.5	86,115	
:46	19.4 rev.	3,355	248	86,180	+140
:46:30	19.3	3,350	245	86,150	+140
:47	19.2	3,345	239	86,090	+140
:47:30	19.1	3,340	233	86,030	+140
:48	0	0	217	85,870	
:48:30	0	0	211.5	85,815	
:49	0	0	204	85,740	
:49:30	0	0	195	85,650	
:50	0	0	186	85,560	
:50:30	0	0	178	85,480	
:51	0	0	169	85,390	
:51:30	0	0	158	85,280	
:52	0	0	148	85,180	
:52:30	0	0	140	85,100	

Cell refilled at 1:55 P.M. Ratio arms 11,000 ohms. Galvanometer zero 250. Current reversed. Circuit closed at 2:19. Balanced at 2:22 with 84,800 ohms. 400 ohms increase = 40 mm. decrease.

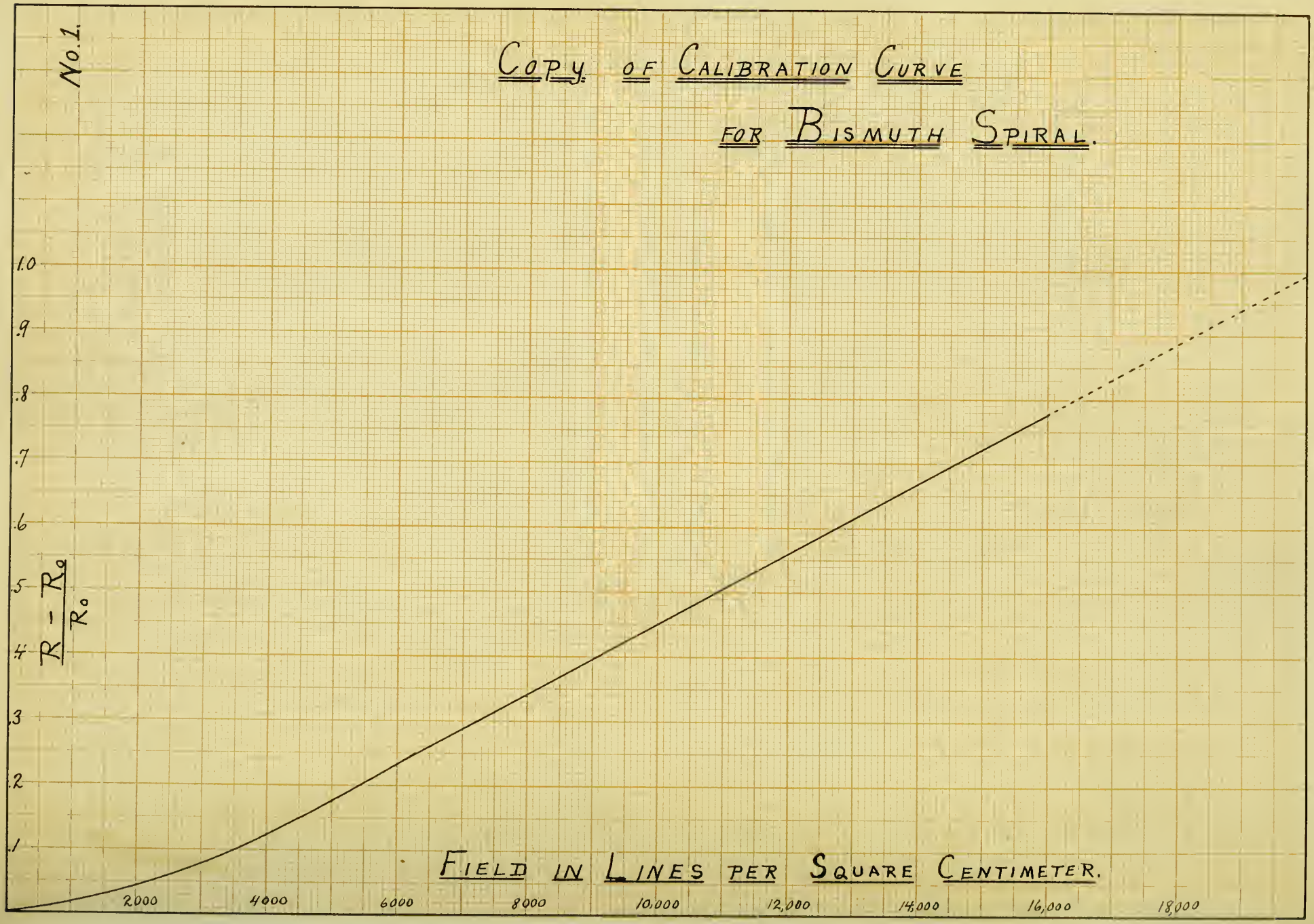
T	I	H	G	R	A
2:22:30	0	0	246	84,840	
:23	0	0	240	84,900	
:23:30	0	0	234	84,960	
:24	0	0	229	85,010	
:24:30	0	0	225	85,050	
:25	0	0	221	85,090	

T	I	H	G	R	A
2:25:30	0	0	217	85,130	
:26	0	0	214	85,160	
:26:30	0	0	211	85,190	
:27	0	0	207	85,230	
:27:30	0	0	202	85,280	
:28	19.3 dir.	3,350	197	85,330	- 40
:28:30	19.3	3,350	192	85,380	- 60
:29	19.3	3,350	186	85,440	- 70
:29:30	19.3	3,350	181	85,490	- 80
:30	0	0	168	85,620	
:30:30	0	0	167	85,630	
:31	0	0	164	85,660	
:31:30	0	0	163	85,670	
:32	0	0	163	85,670	
:32:30	0	0	165	85,650	
:33	0	0	167	85,630	
:33:30	0	0	170.5	85,595	
:34	0	0	173	85,570	
:34:30	0	0	176.5	85,535	
:35	19.0 rev.	3,330	180	85,500	- 30
:35:30	19.0	3,330	181	85,490	- 25
:36	19.0	3,330	182	85,480	- 10
:36:30	19.0	3,330	185	85,450	- 20
:37	0	0	195	85,450	
:37:30	0	0	191	85,390	
:38	0	0	197	85,330	
:38:30	0	0	203	85 270	

T	I	H	G	R	A
2:39	0	0	210	85,200	
:39:30	0	0	218	85,120	
:40	0	0	226	85,040	
:40:30	0	0	233	84,970	
:41	0	0	242	84,880	
:41:30	0	0	250	84,800	

No. 1.

Copy of Calibration Curve for Bismuth Spiral.



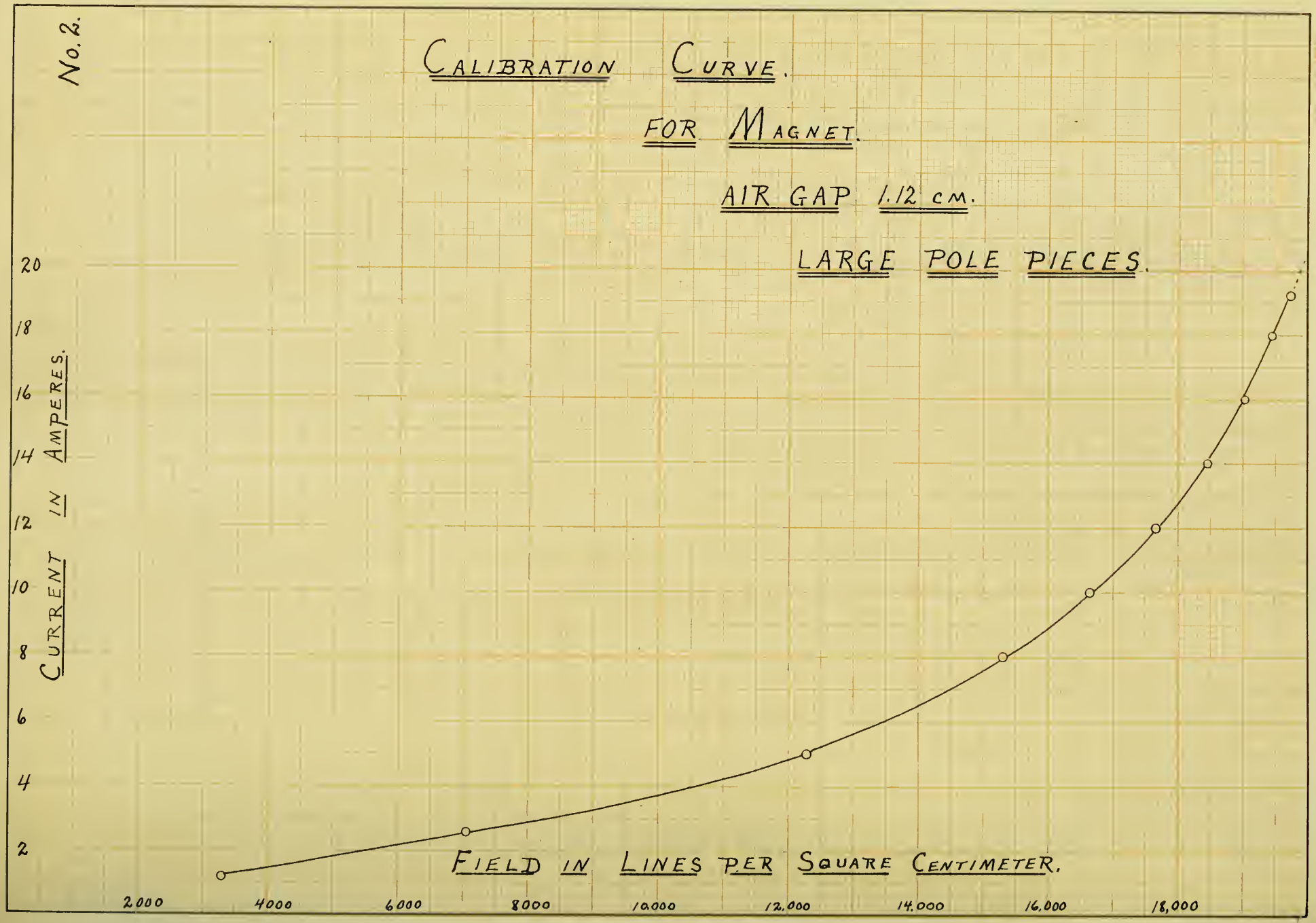
No. 2.

Calibration Curve.

For Magnet.

Air Gap 1.12 cm.

Large Pole Pieces.



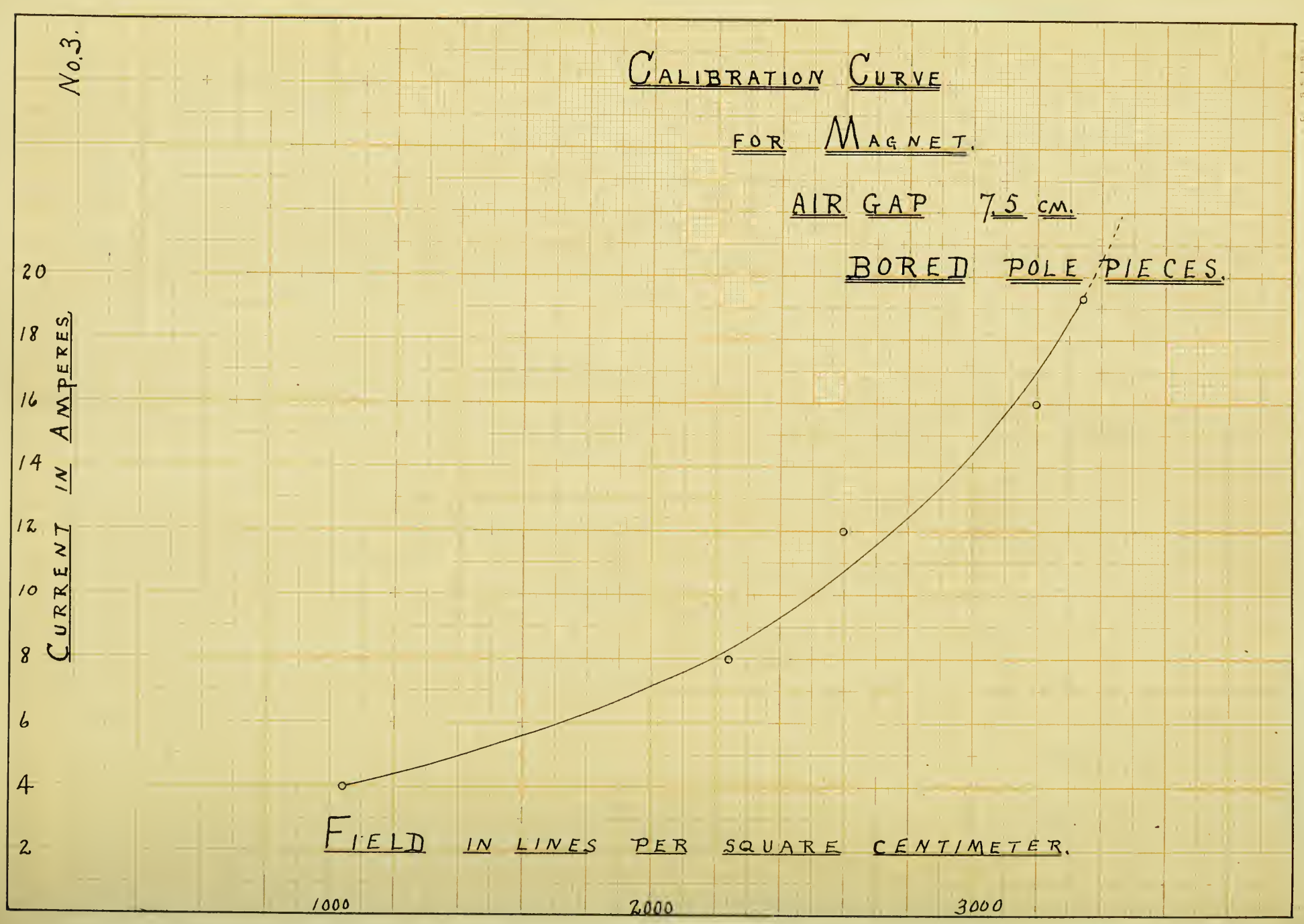
No. 3.

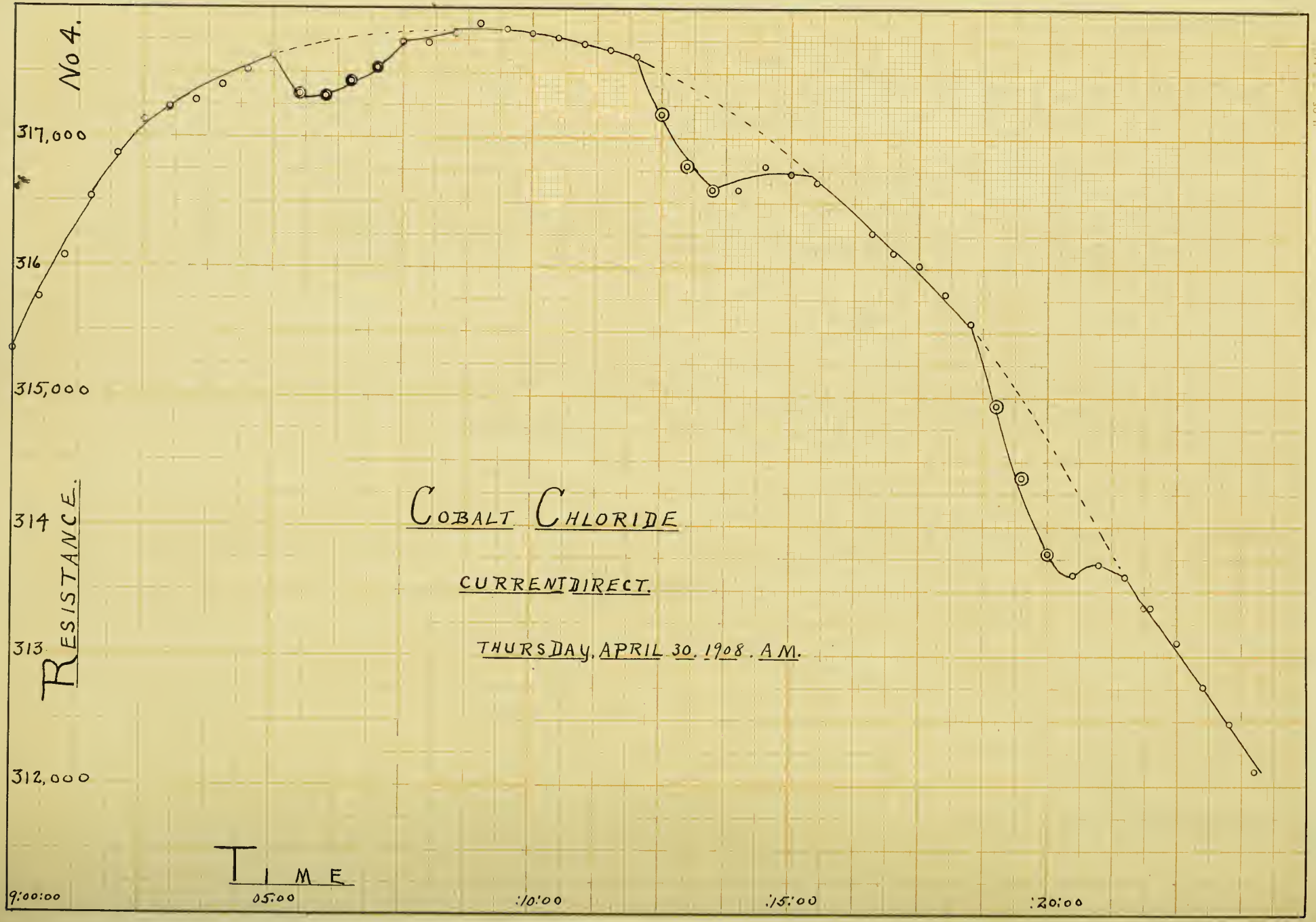
Calibration Curve

for Magnet.

AIR GAP 7.5 cm.

BORED POLE PIECES.

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314
313
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COBALT CHLORIDE
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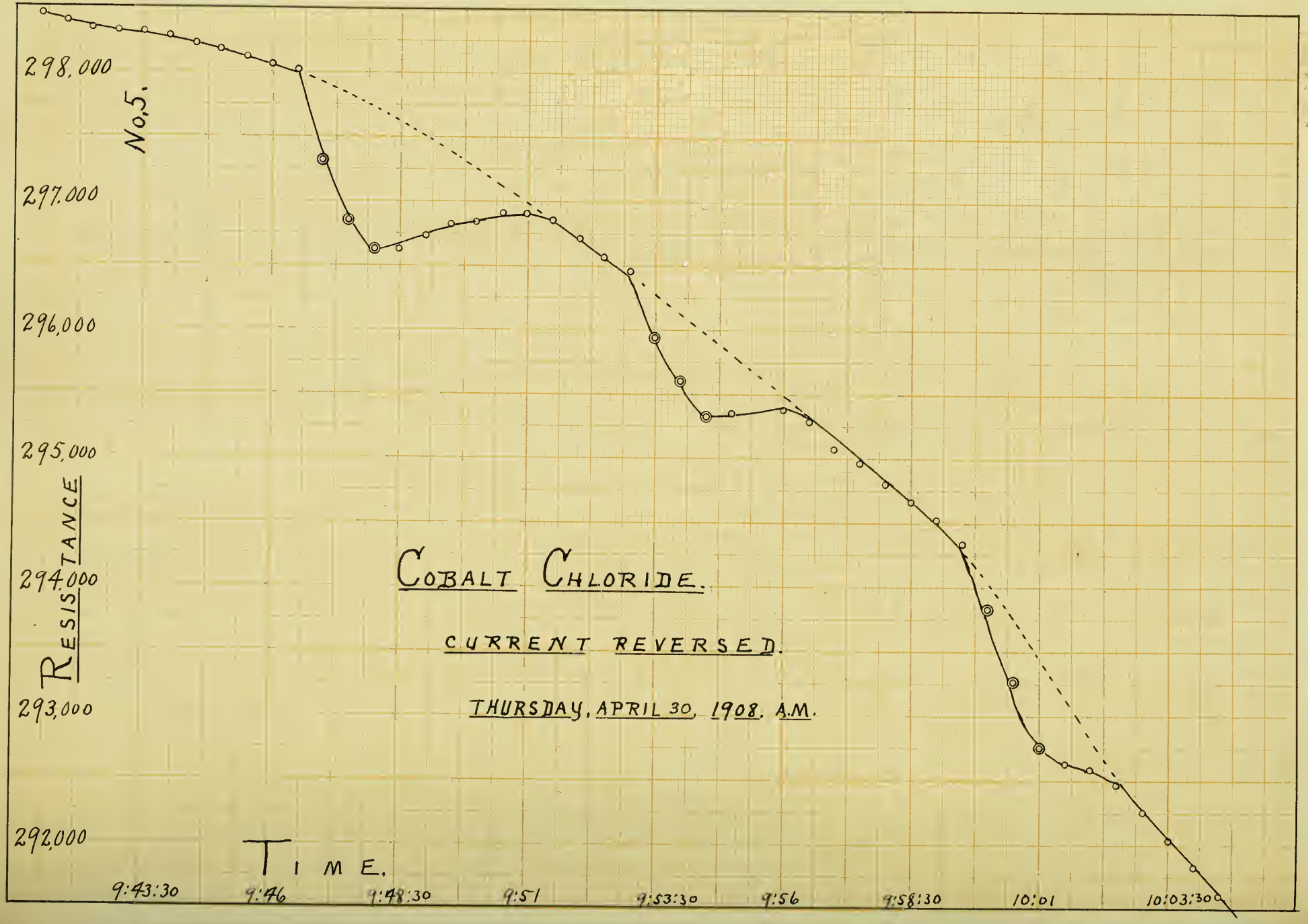
THURSDAY, APRIL 30. 1908. A.M.
TIME
9:00:00
05:00
:10:00
:15:00
:20:00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CURRENT REVERSED.
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TIME.
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9:46
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9:51
9:53:30
9:56
9:58:30
10:01
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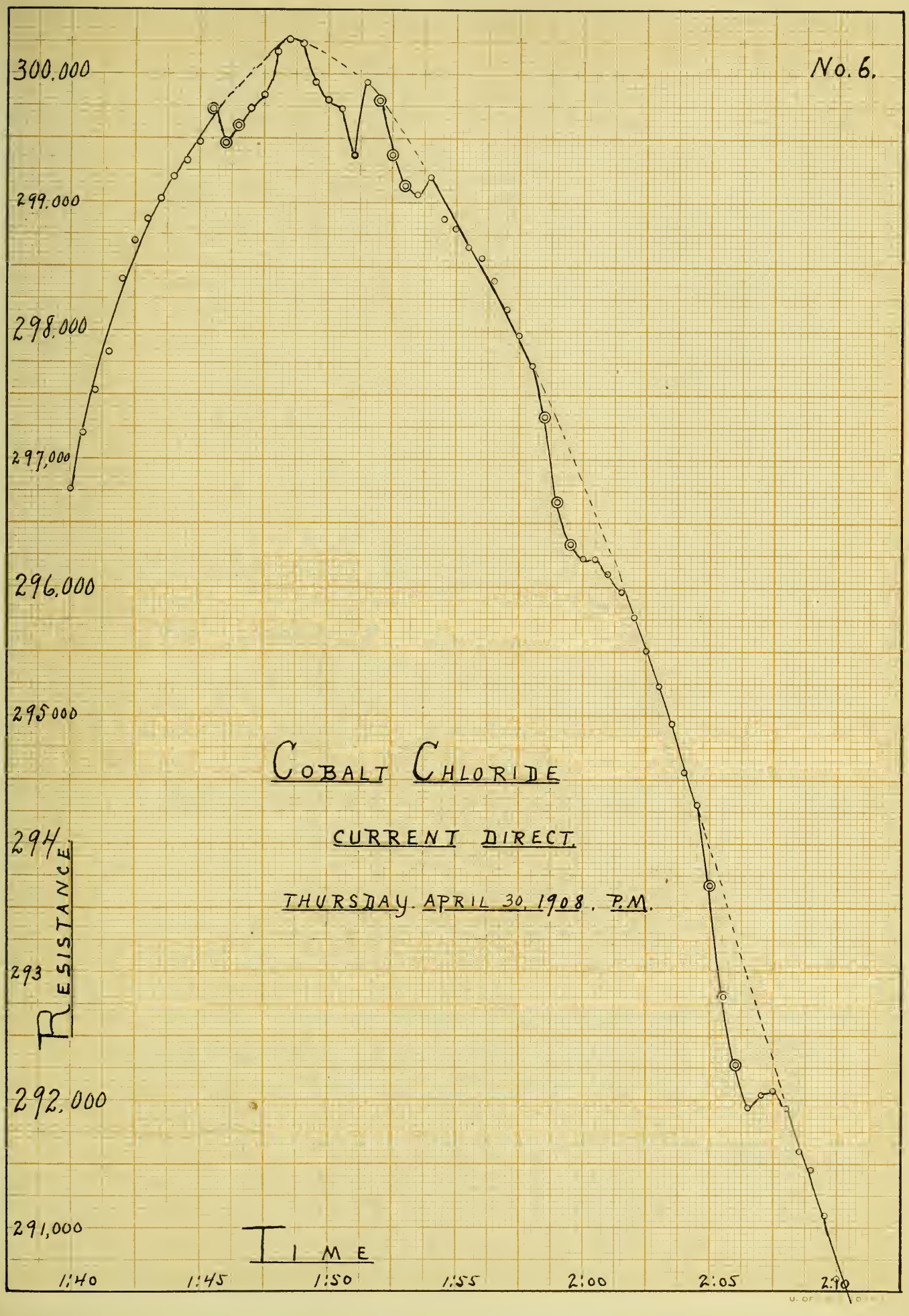
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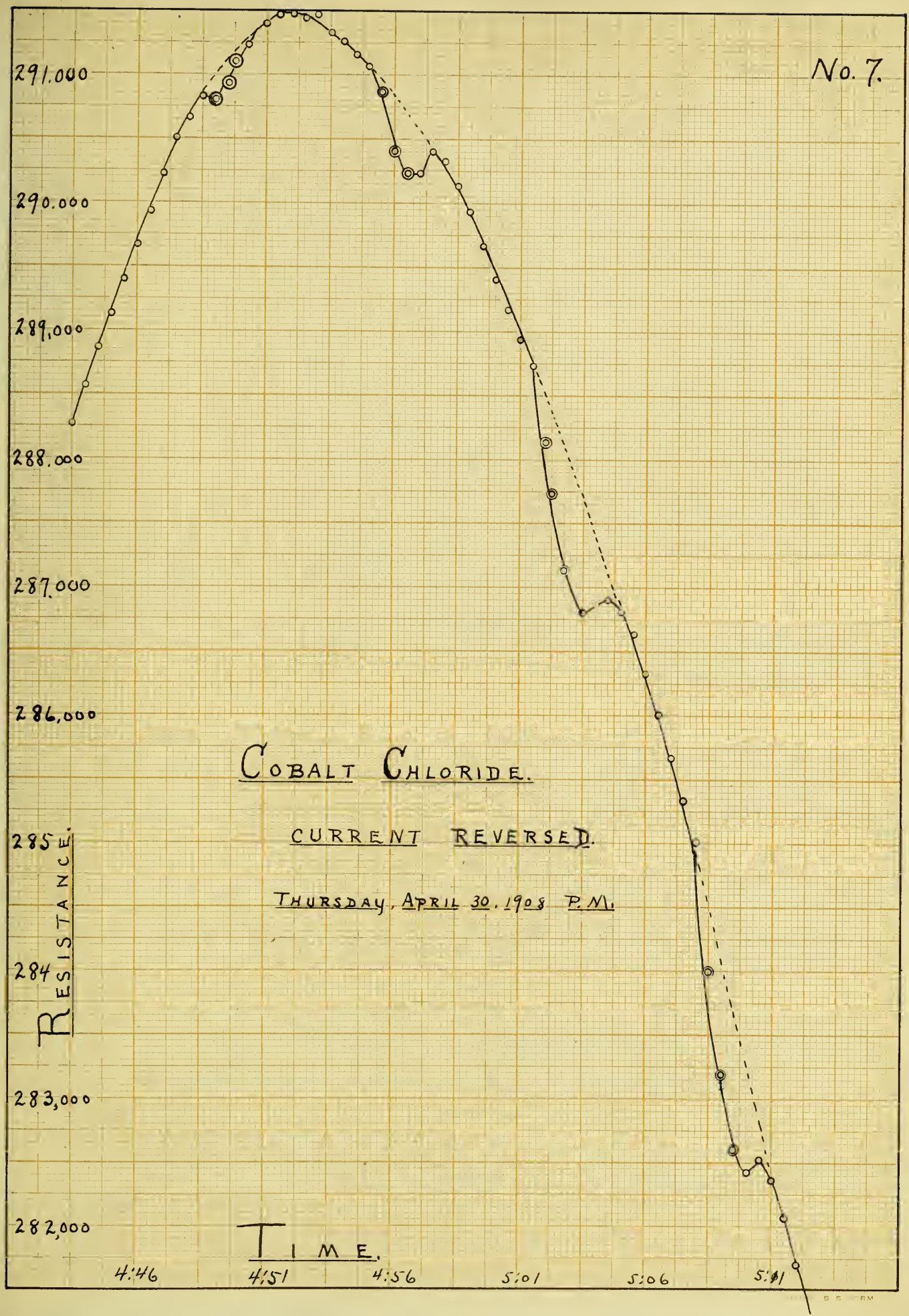
COBALT CHLORIDE
CURRENT DIRECT.
THURSDAY. APRIL 30. 1908. P.M.
TIME
1:40
1:45
1:50
1:55
2:00
2:05
2:10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285
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283,000
282,000
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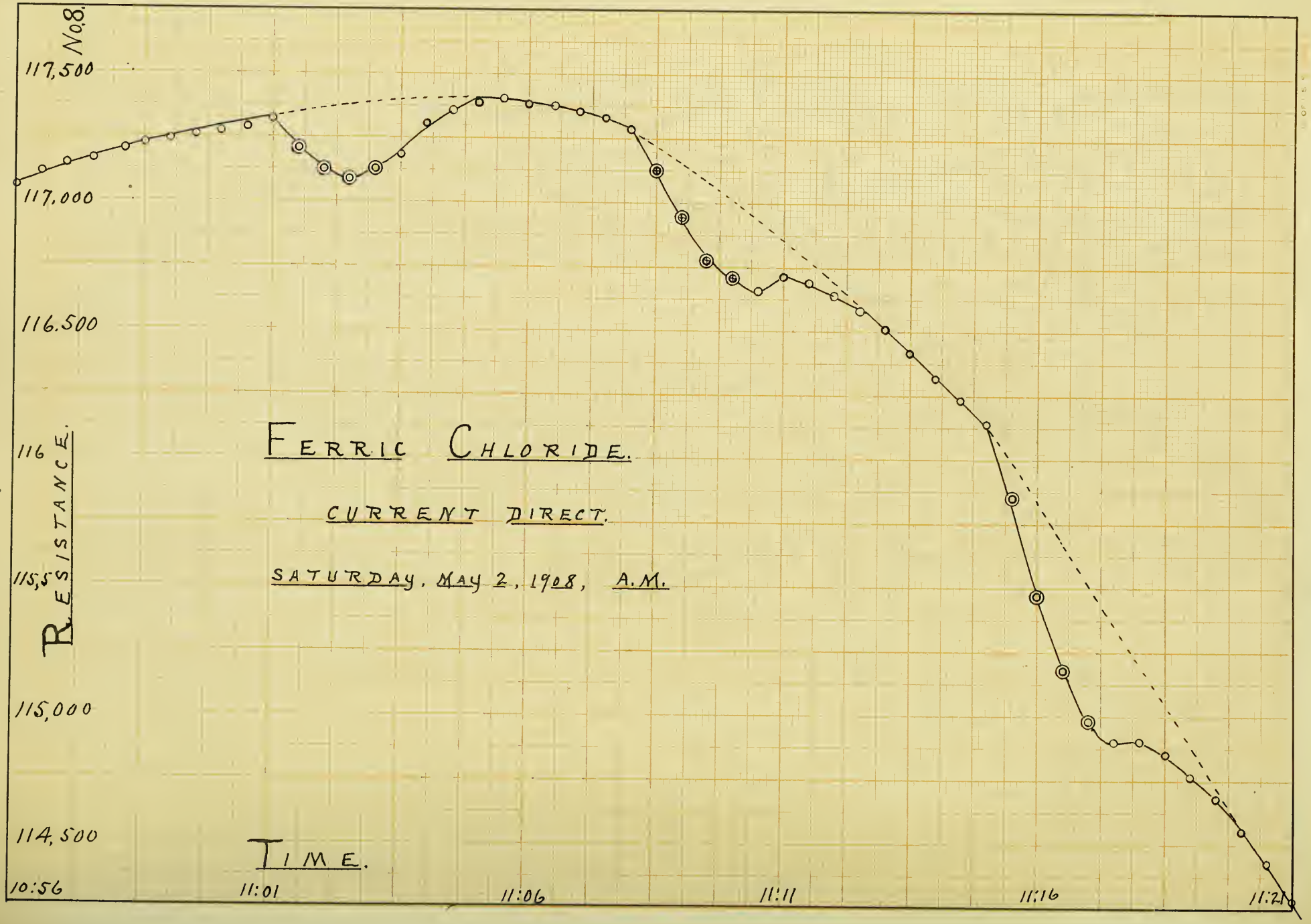
COBALT CHLORIDE.
CURRENT REVERSED.
THURSDAY, APRIL 30. 1908 P.M.
TIME.
4:46
4:51
4:56
5:01
5:06
5:11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116
115,5
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FERRIC CHLORIDE.
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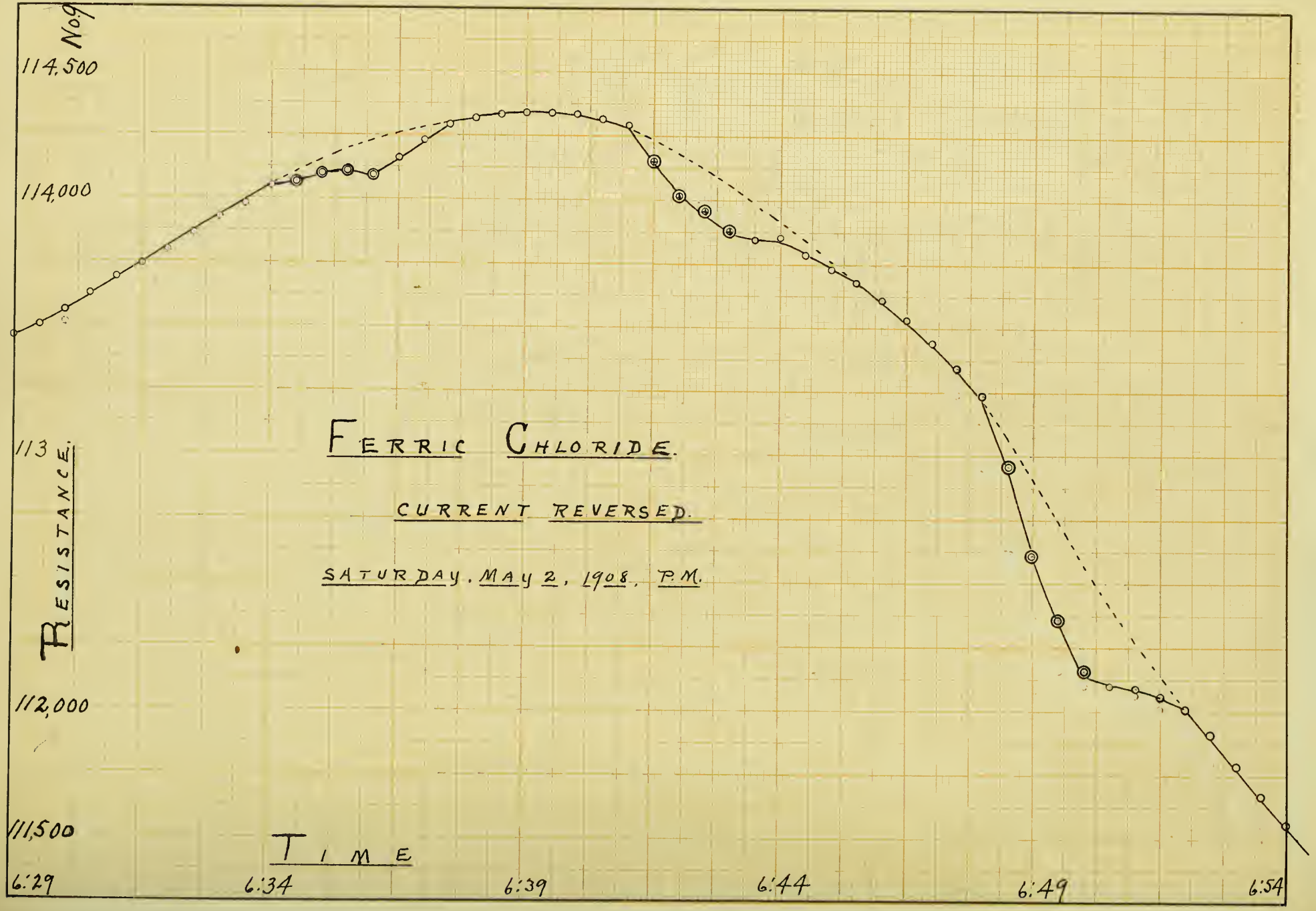
SATURDAY, MAY 2, 1908, A.M.
TIME.
10:56
11:01
11:06
11:11
11:16
11:21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FERRIC CHLORIDE.
CURRENT REVERSED.
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TIME
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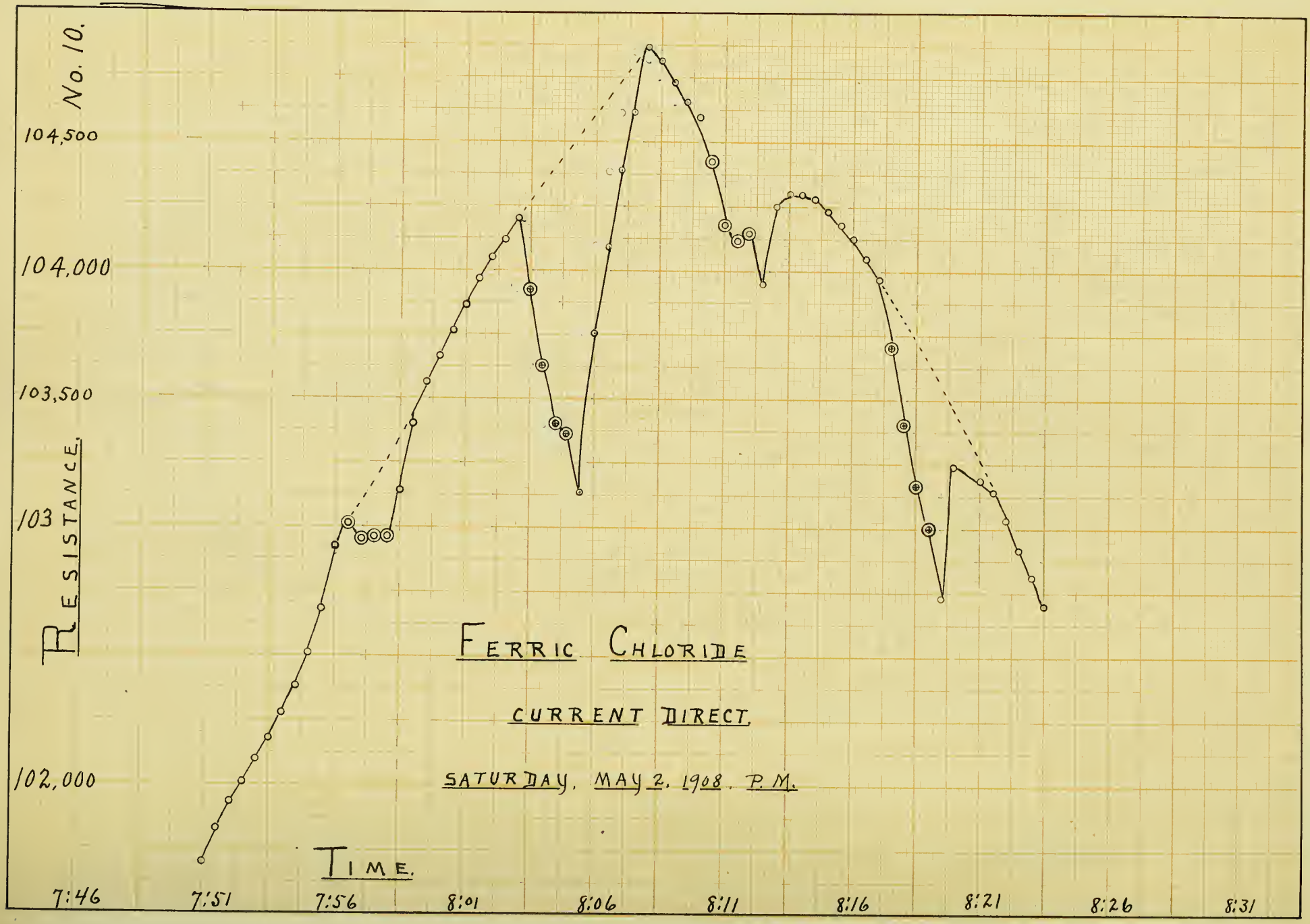
6:34
6:39
6:44
6:49
6:54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FERRIC CHLORIDE
CURRENT DIRECT.
SATURDAY, MAY 2. 1908. P.M.
TIME.
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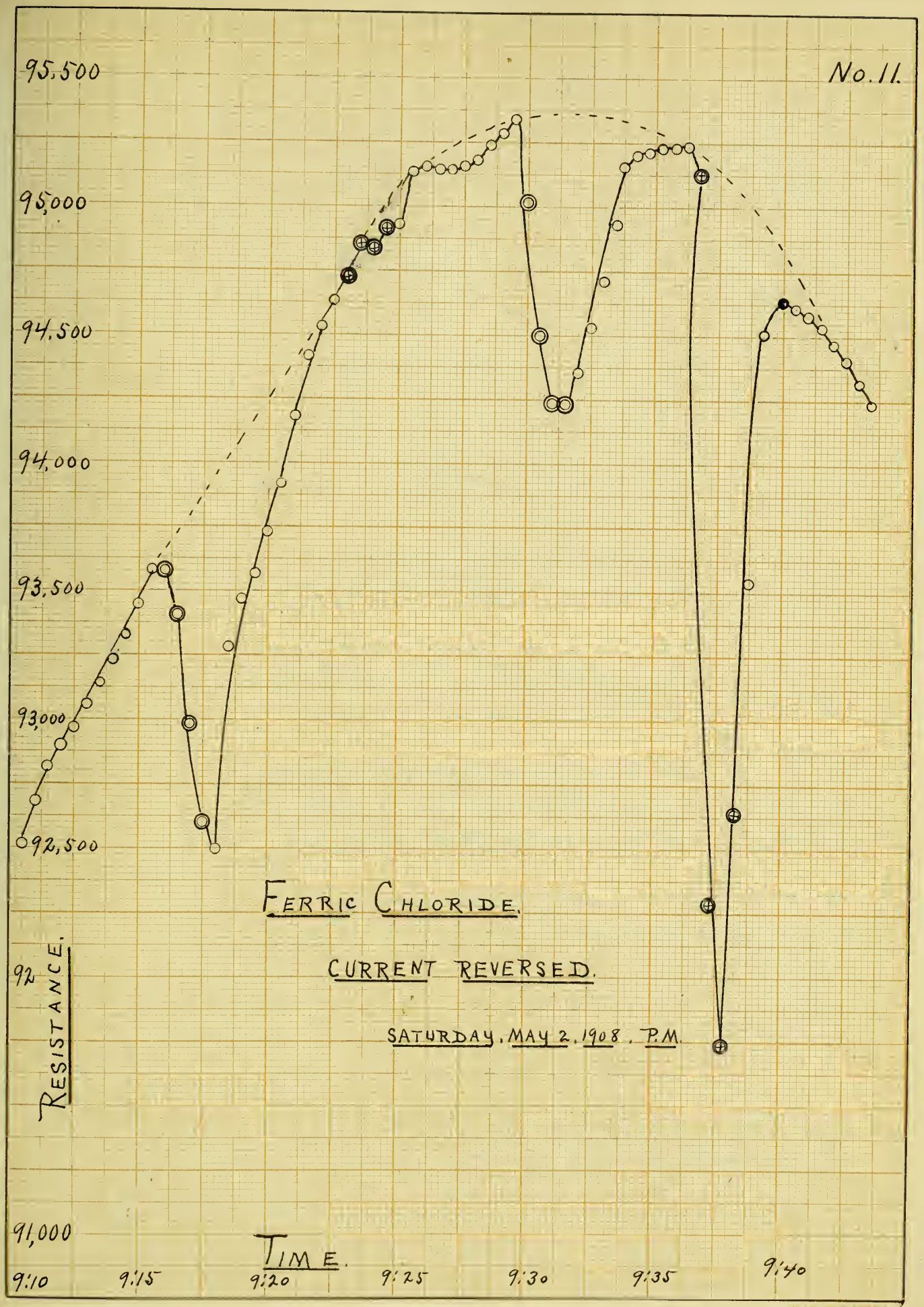
7:56
8:01
8:06
8:11
8:16
8:21
8:26
8:31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FERRIC CHLORIDE.
CURRENT REVERSED.
SATURDAY, MAY 2, 1908, P.M.
TIME.
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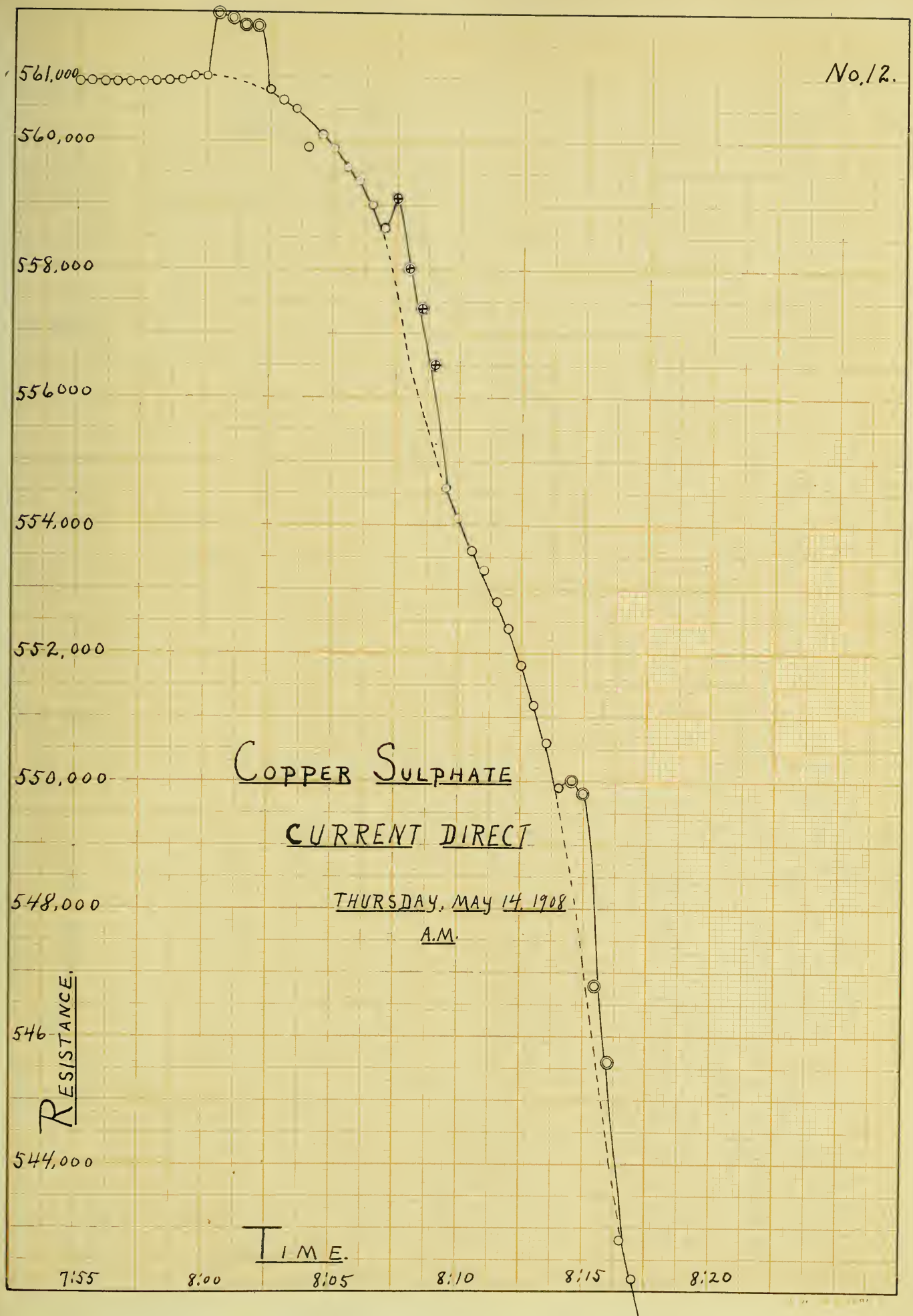
9:15
9:20
9:25
9:30
9:35
9:40

No. 12.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546
544,000
RESISTANCE.
COPPER SULPHATE
CURRENT DIRECT
THURSDAY. MAY 14. 1908
A.M.
TIME.
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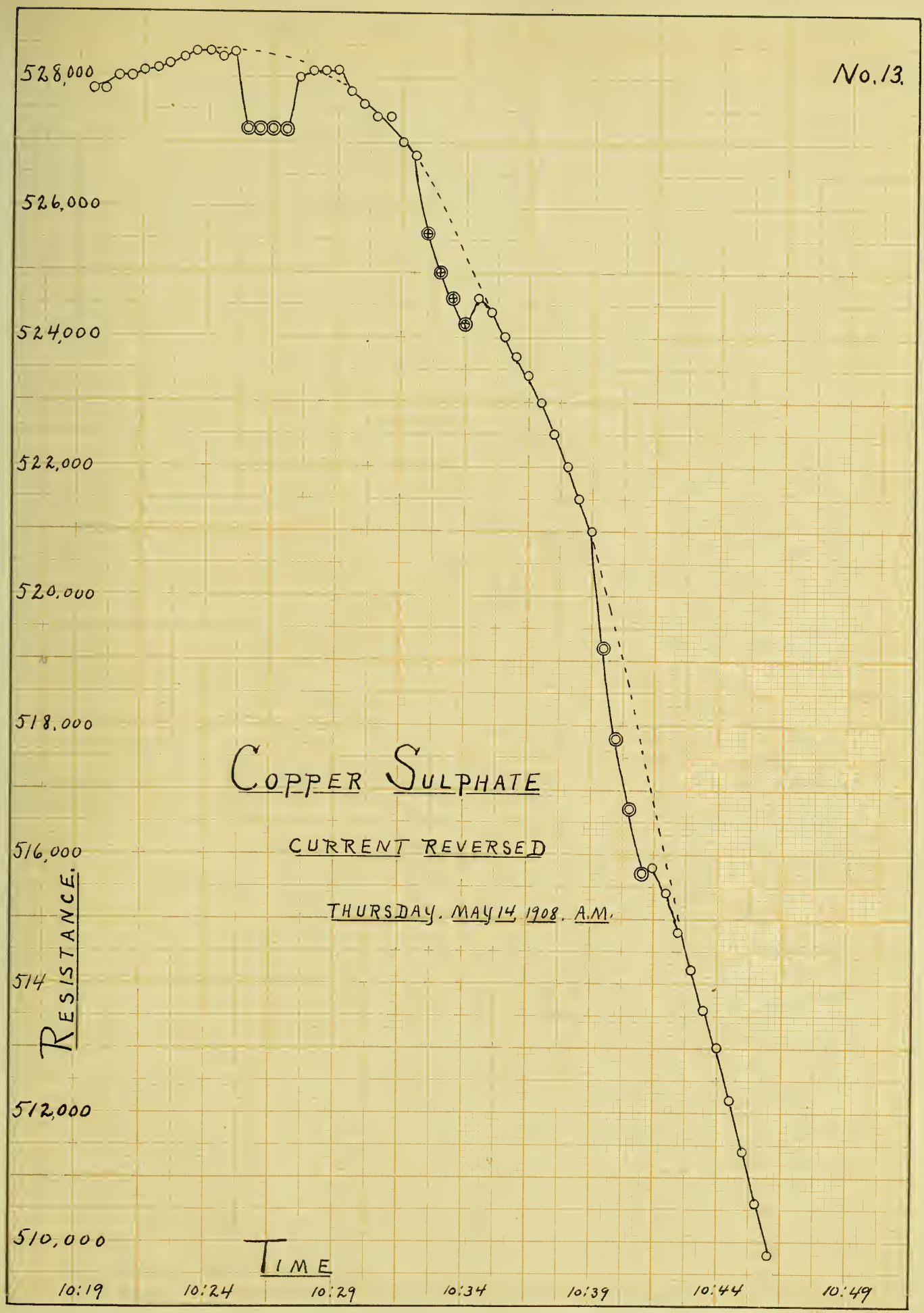
8:00
8:05
8:10
8:15
8:20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516,000
514
512,000
510,000
RESISTANCE.
COPPER SULPHATE
CURRENT REVERSED
THURSDAY. MAY 14, 1908. A.M.
TIME
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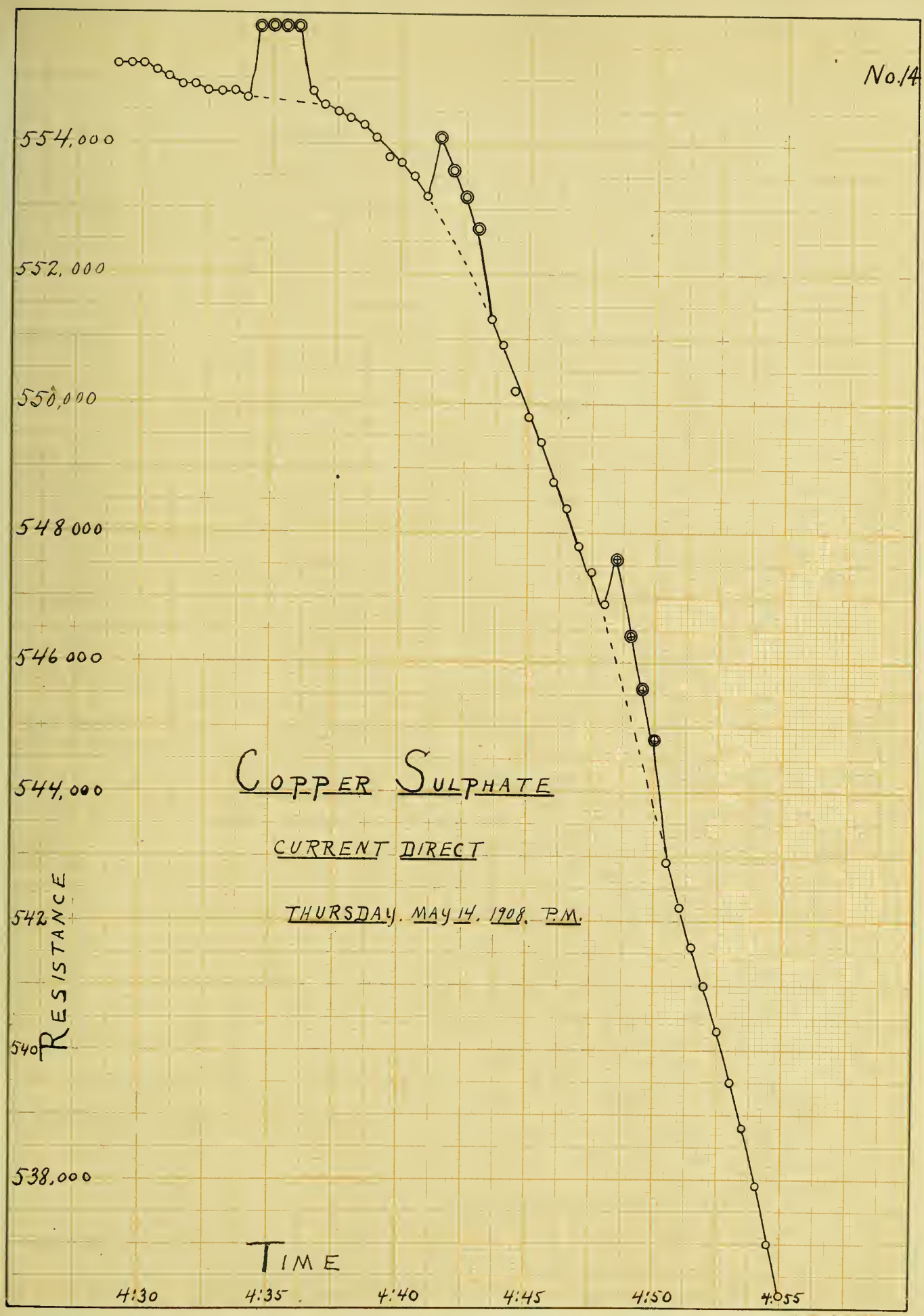
10:24
10:29
10:34
10:39
10:44
10:49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540
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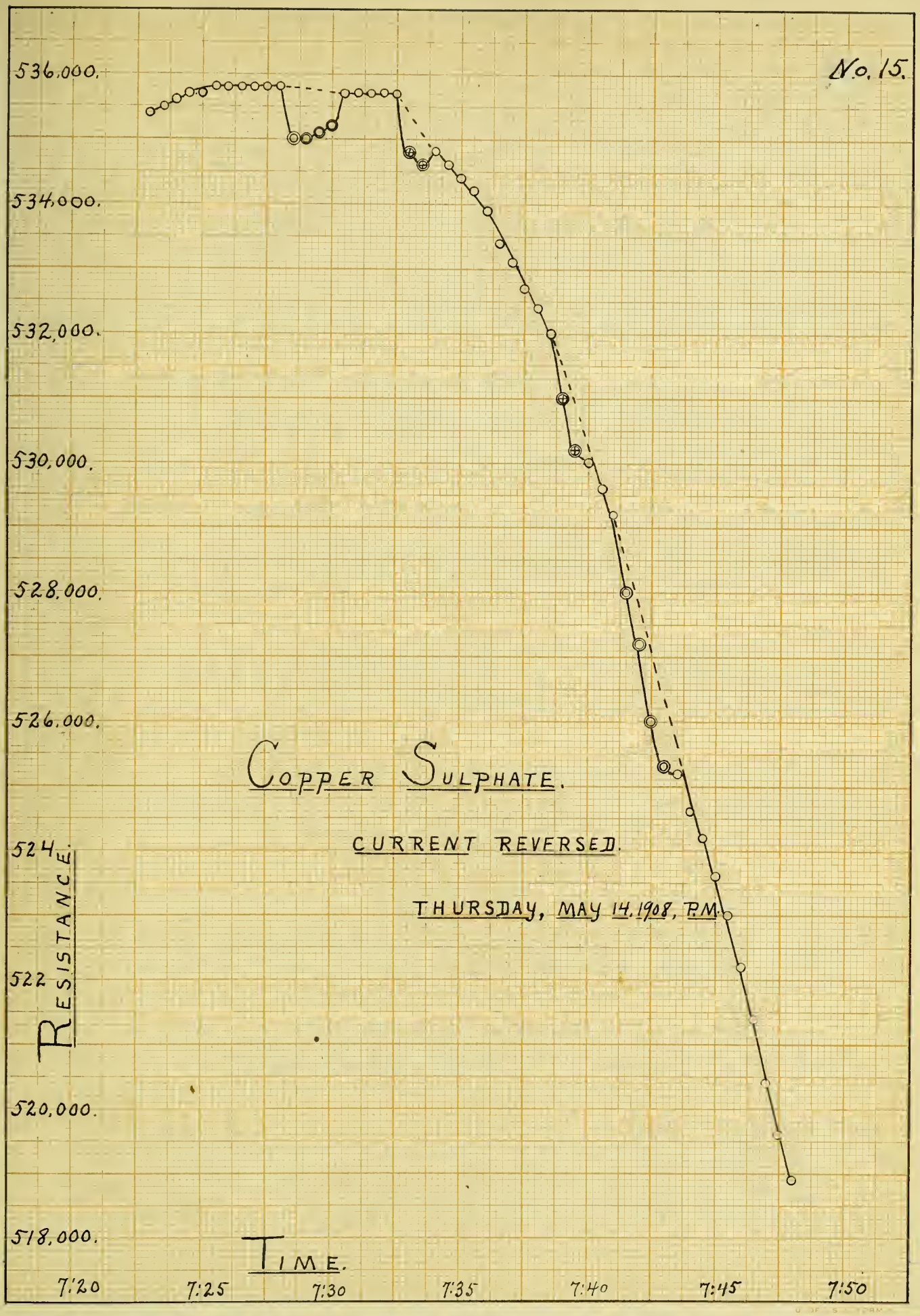
RESISTANCE
COPPER SULPHATE
CURRENT DIRECT
THURSDAY. MAY 14. 1908. P.M.
TIME
4:30
4:35
4:40
4:45
4:50
4:55

No. 15.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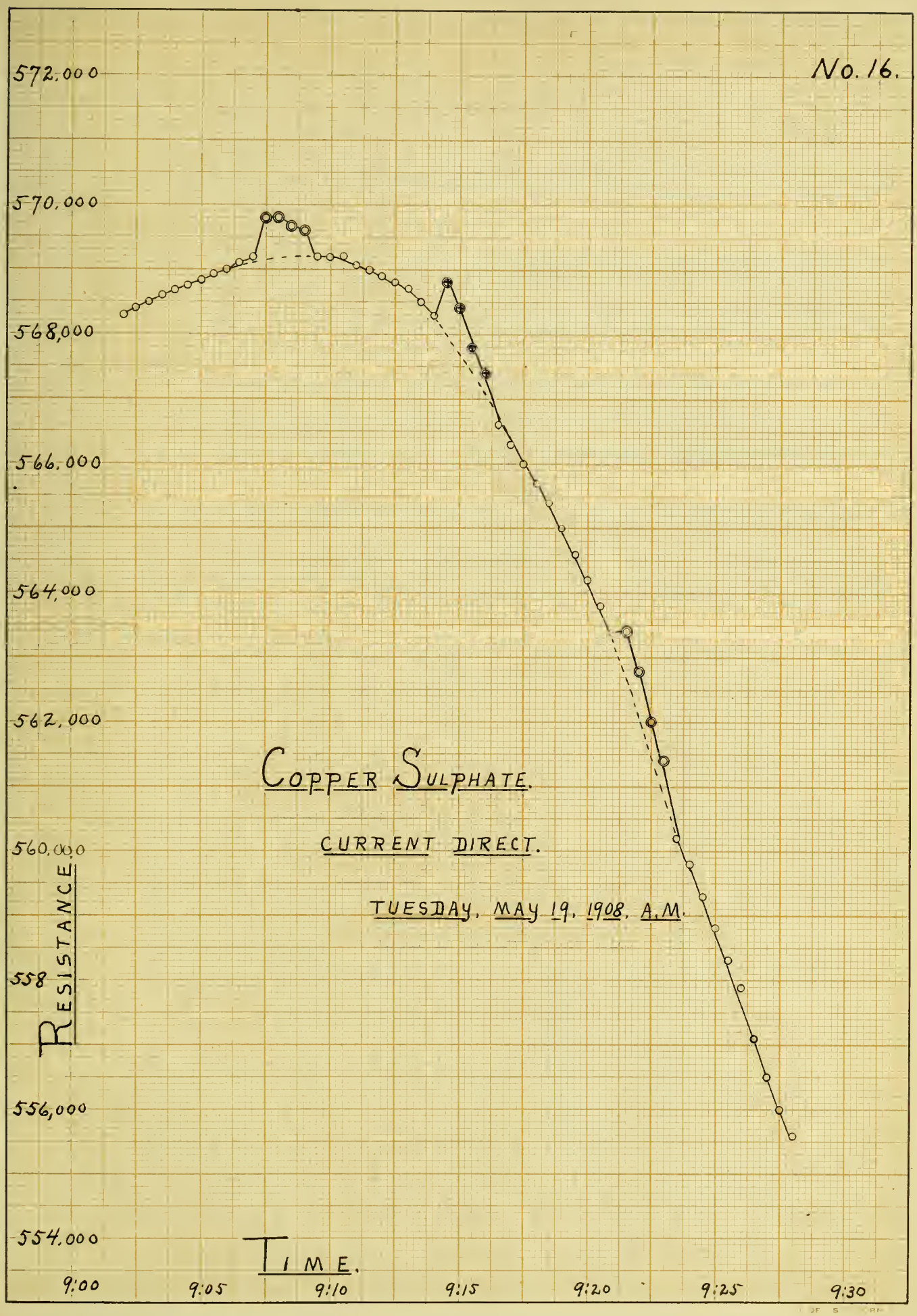
530,000.
528,000.
526,000.
524.
522
520,000.
518,000.
RESISTANCE.
COPPER SULPHATE.
CURRENT REVERSED.
THURSDAY, MAY 14, 1908, P.M.
TIME.
7:20
7:25
7:30
7:35
7:40
7:45
7:50

No. 16.

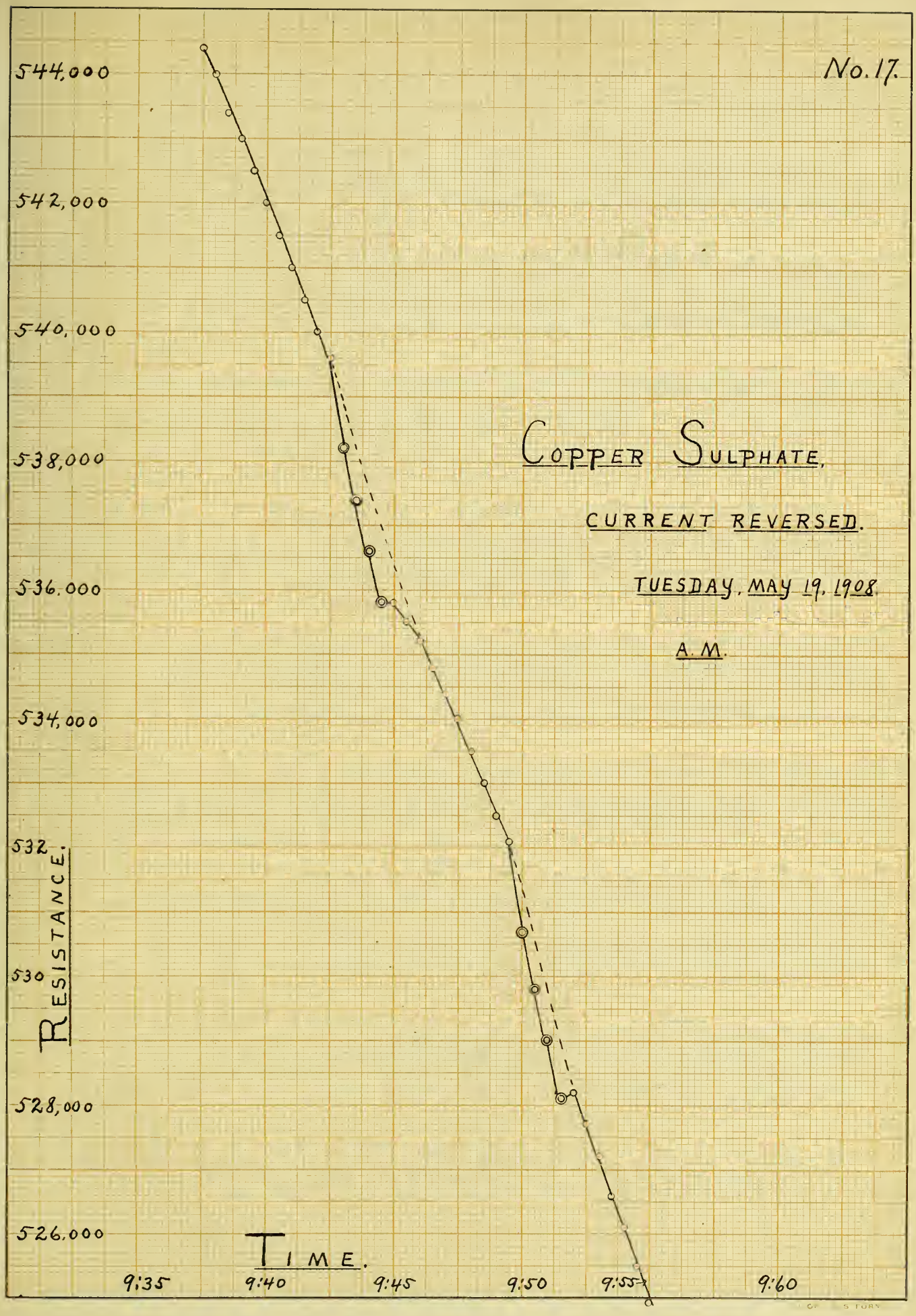


COPPER SULPHATE.

CURRENT DIRECT.

TUESDAY, MAY 19, 1908. A.M.

No. 17.

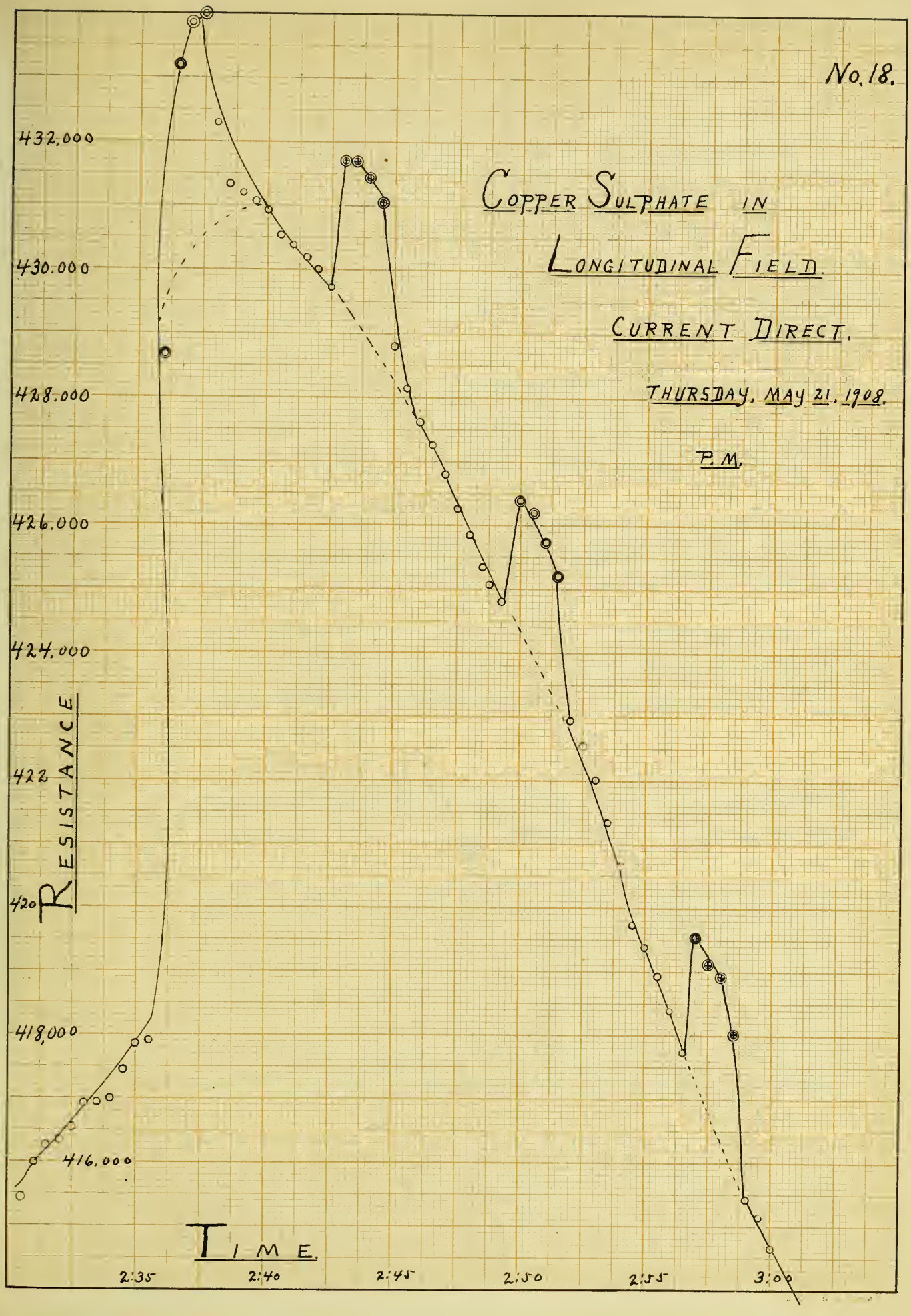


COPPER SULPHATE.

CURRENT REVERSED.

TUESDAY, MAY 19, 1908.

A. M.


No. 18.
COPPER SULPHATE IN
LONGITUDINAL FIELD.
CURRENT DIRECT.
THURSDAY, MAY 21, 1908.
P. M.
432.000
430.000
428.000
426.000
424.000
422
420
418.000
416.000
RESISTANCE
TIME.
2:35
2:40
2:45
2:50
2:55
3:00

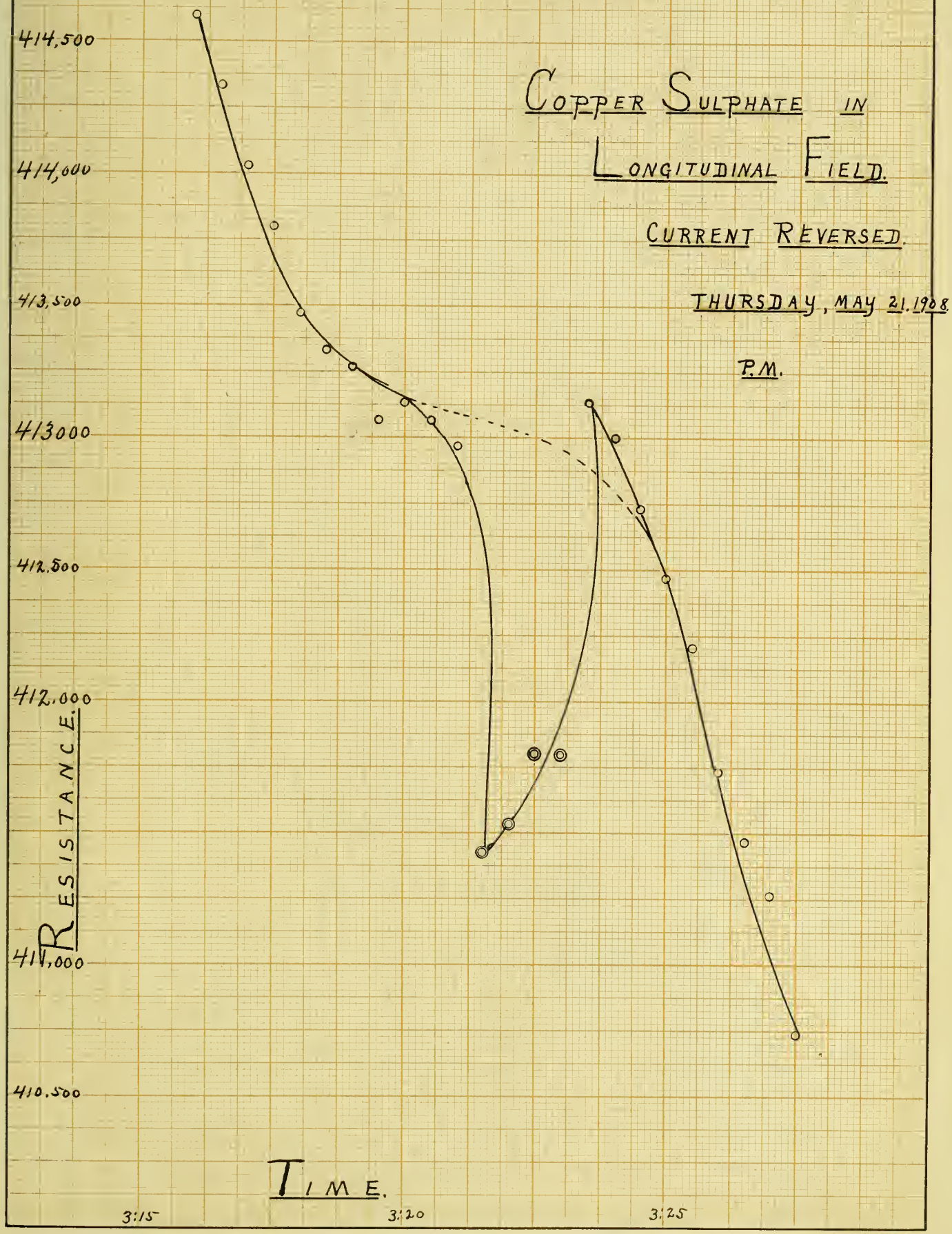
No. 19.

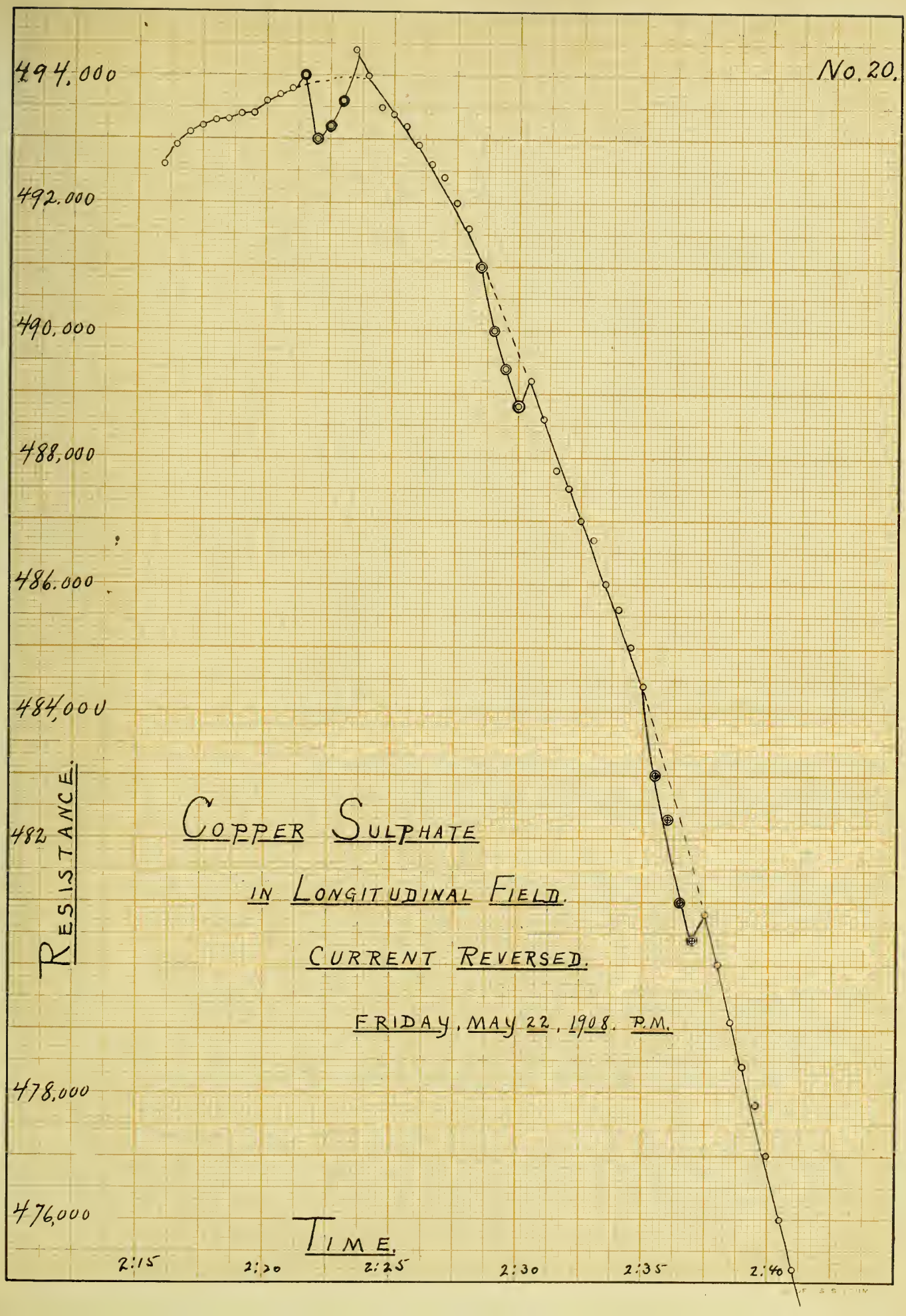
Copper Sulphate in Longitudinal Field.

Current Reversed.

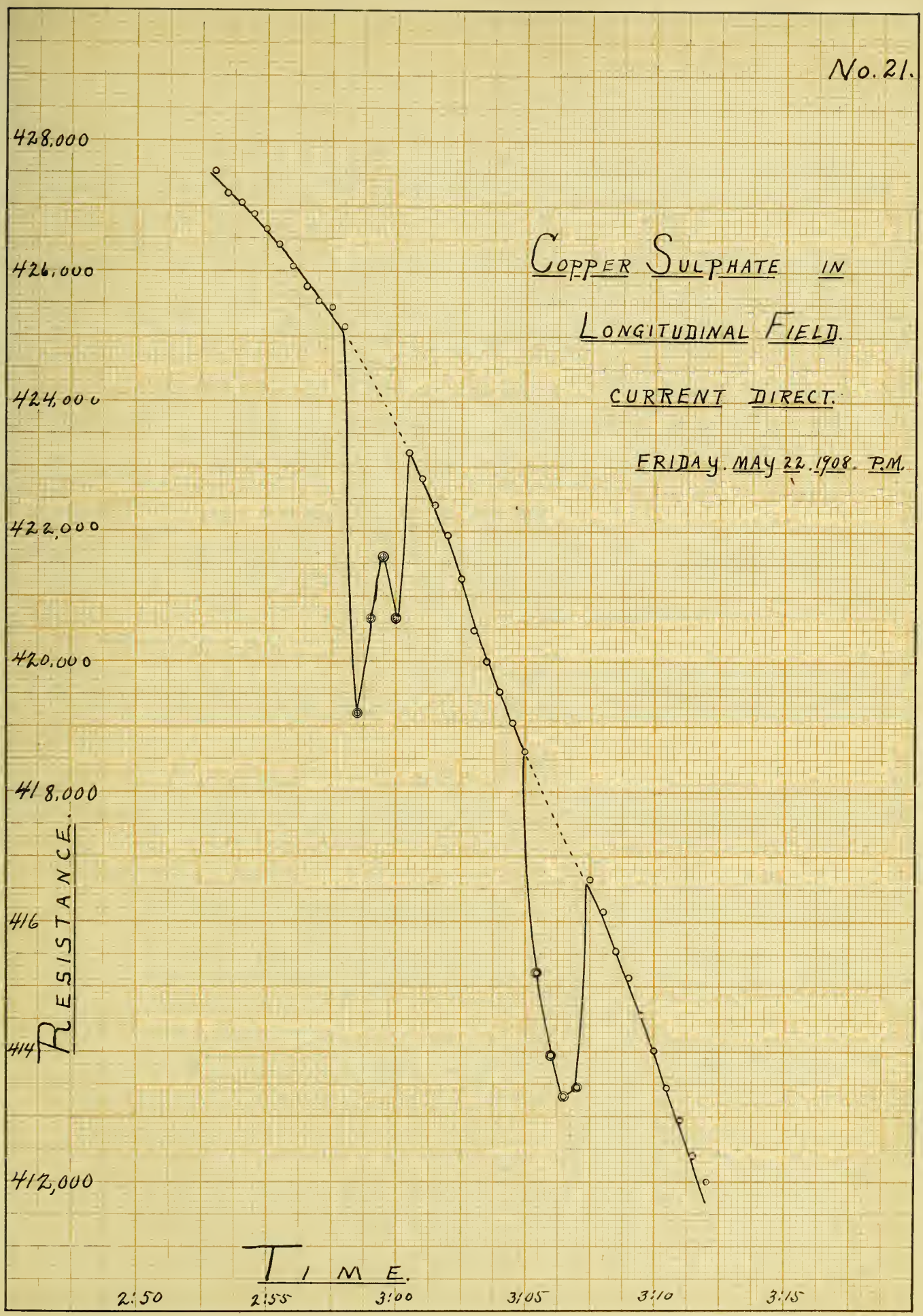
Thursday, May 21. 1908.

P.M.




No. 20.
494.000
492.000
490.000
488.000
486.000
484.000
482
478.000
476.000
RESISTANCE.
COPPER SULPHATE
IN LONGITUDINAL FIELD.
CURRENT REVERSED.
FRIDAY, MAY 22, 1908. P.M.
TIME.
2:15
2:20
2:25
2:30
2:35
2:40

No. 21.



COPPER SULPHATE IN LONGITUDINAL FIELD.

CURRENT DIRECT.

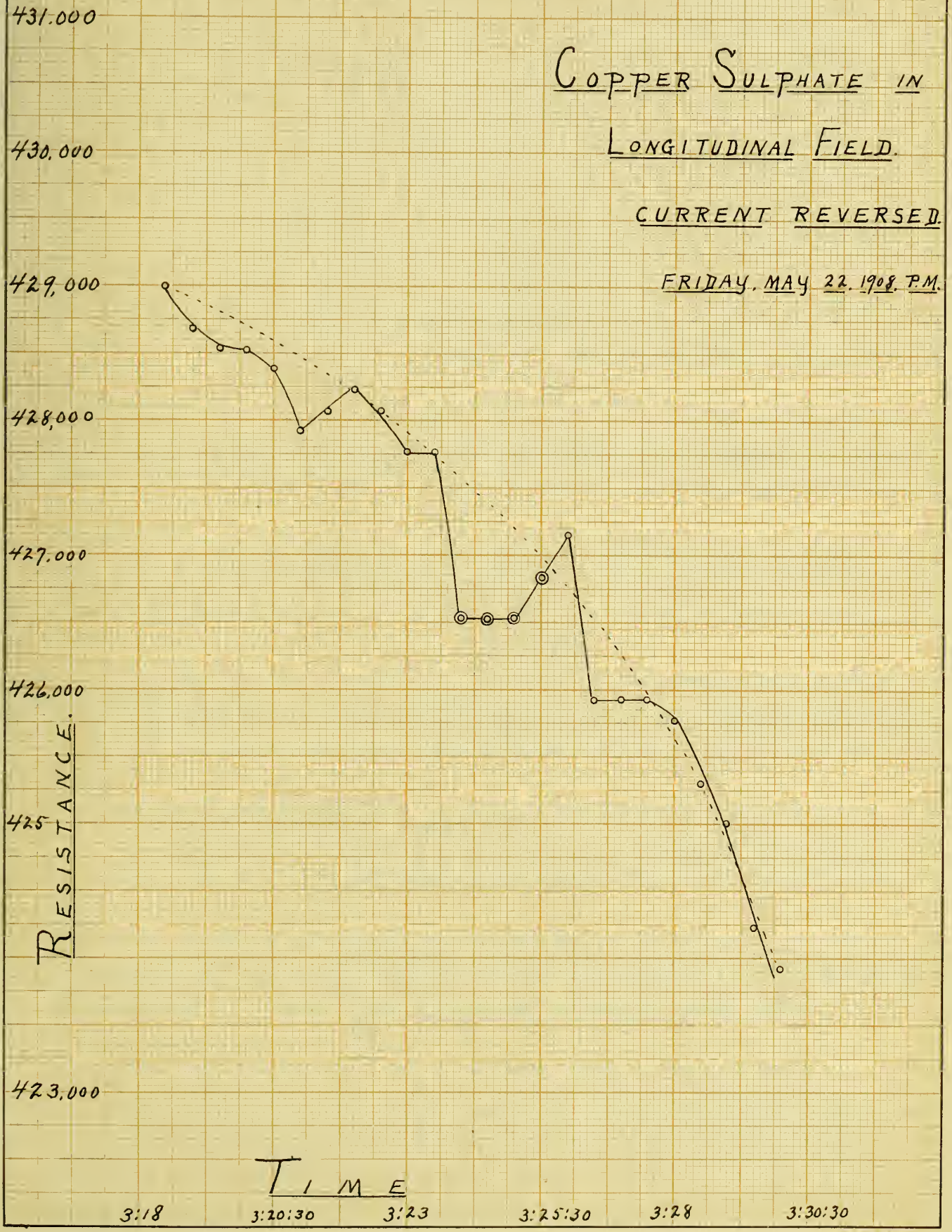
FRIDAY. MAY 22. 1908. P.M.

No. 22.

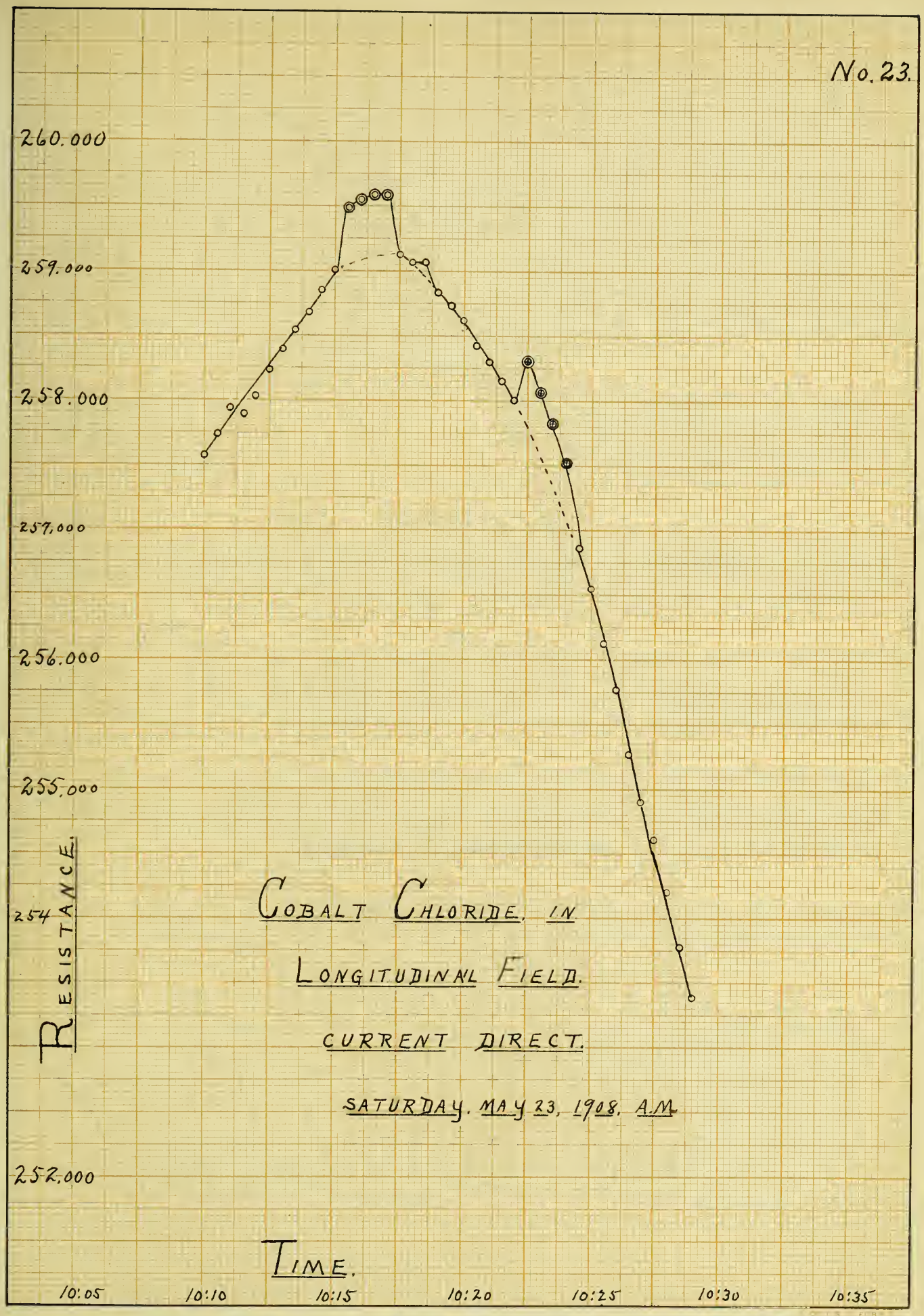
Copper Sulphate in Longitudinal Field.

Current Reversed.

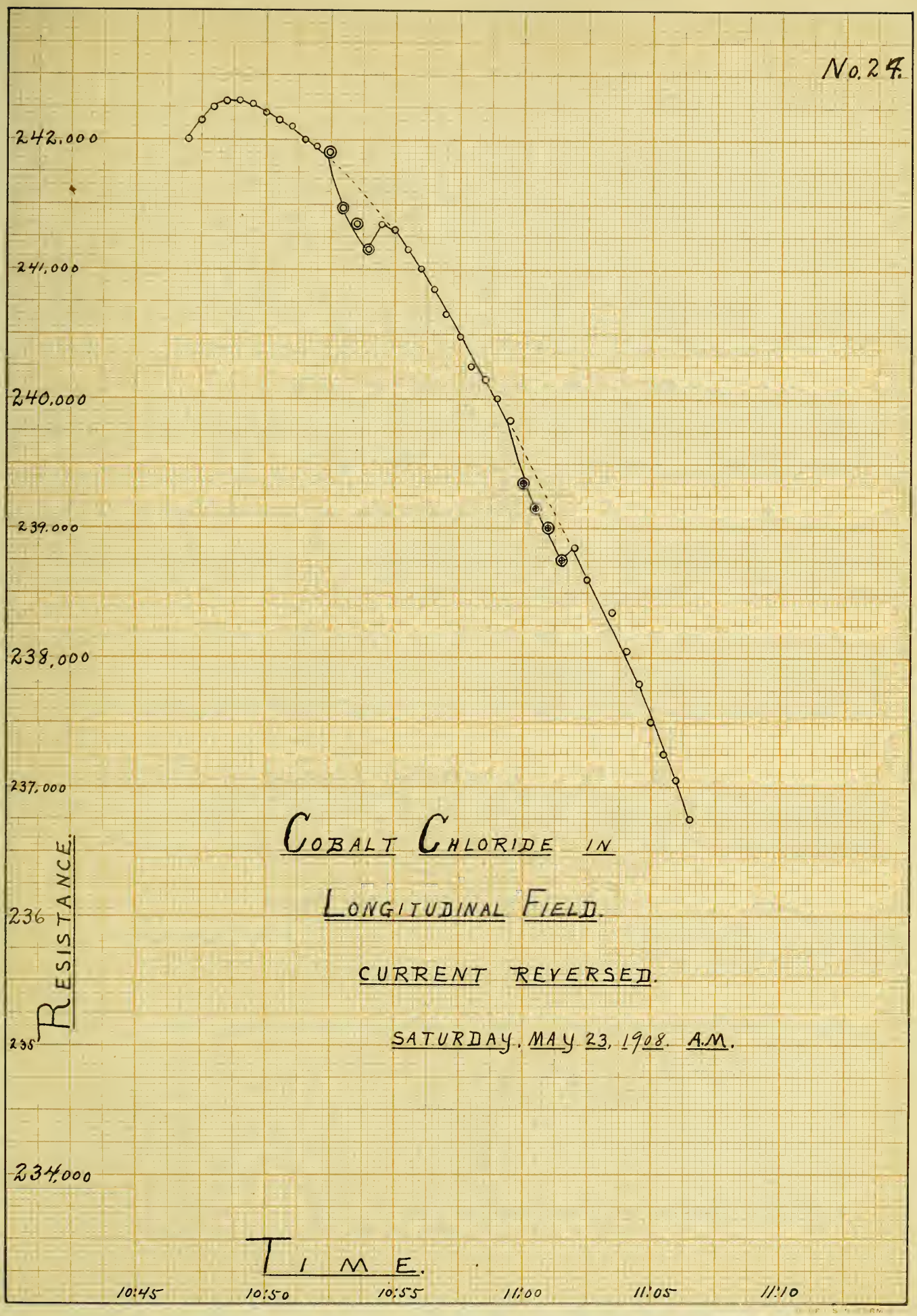
Friday, May 22. 1908. P.M.



No. 23.


260.000
259.000
258.000
257.000
256.000
255.000
254
252.000
RESISTANCE.
COBALT CHLORIDE. IN
LONGITUDINAL FIELD.
CURRENT DIRECT.
SATURDAY. MAY 23, 1908. A.M.
TIME.
10:05
10:10
10:15
10:20
10:25
10:30
10:35

No. 24.



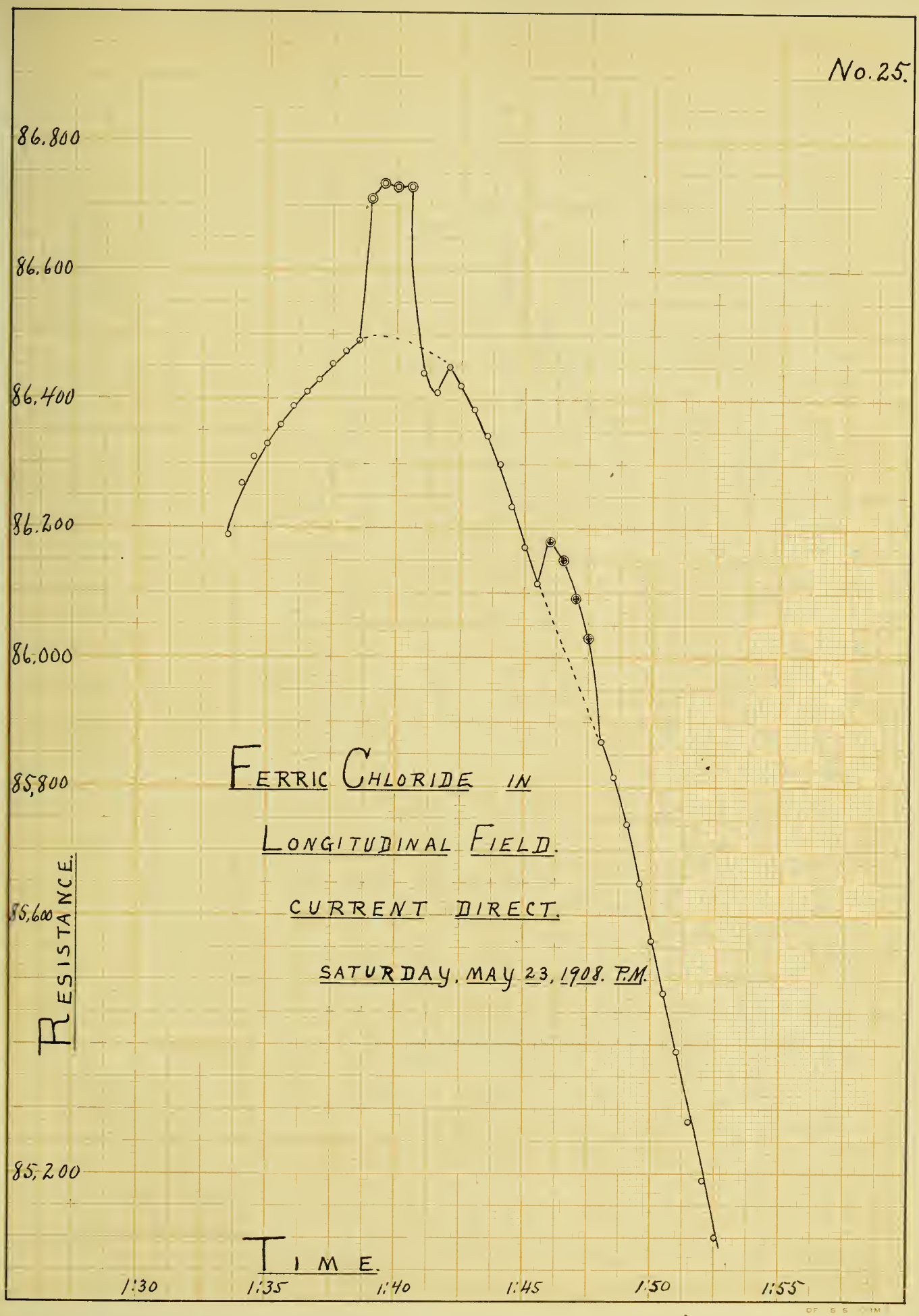
COBALT CHLORIDE IN

LONGITUDINAL FIELD.

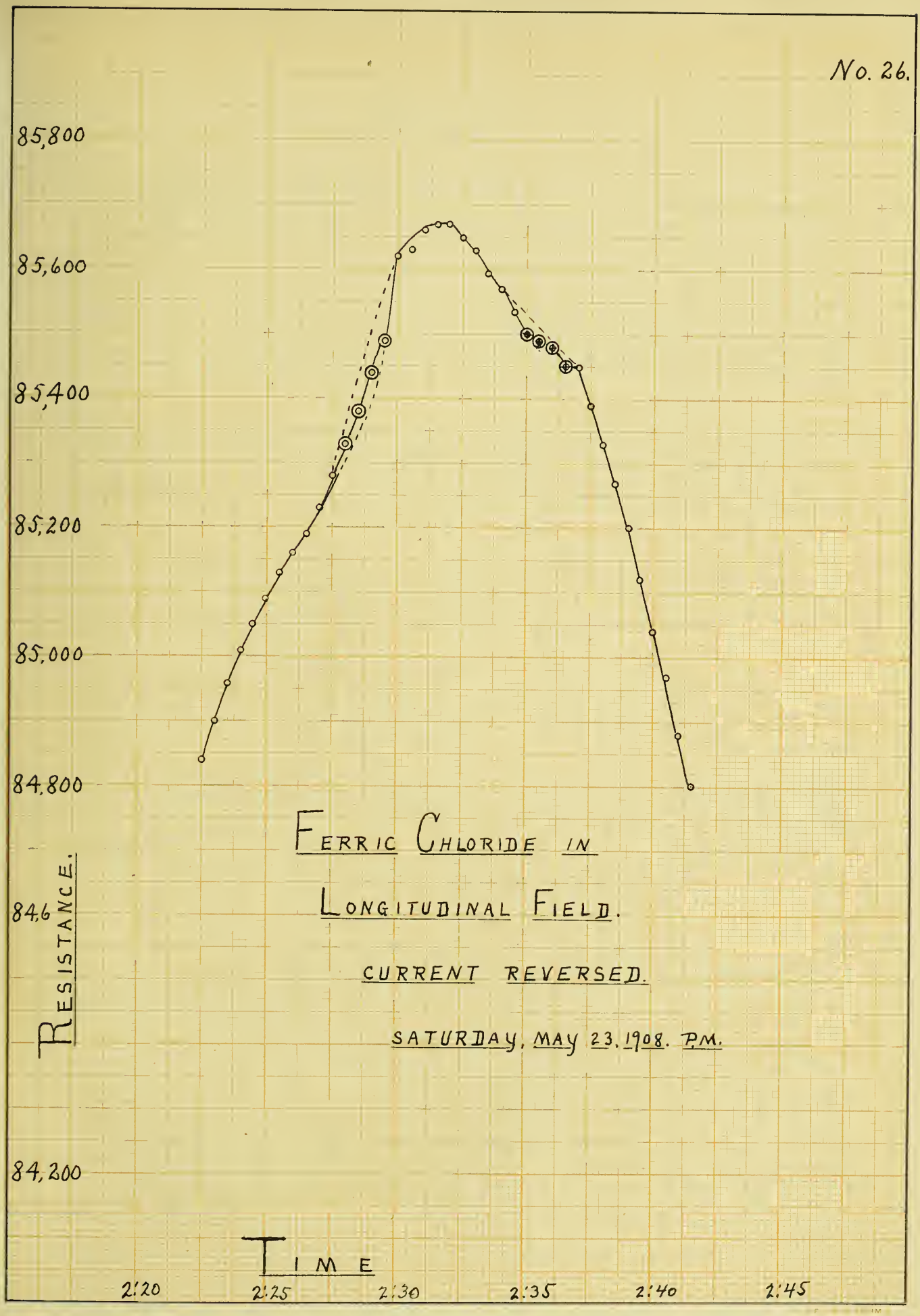
CURRENT REVERSED.

SATURDAY. MAY 23, 1908. A.M.

No. 25.


86.800
86.600
86.400
86.200
86.000
85,800
85,600
85,200
RESISTANCE.
FERRIC CHLORIDE IN
LONGITUDINAL FIELD.
CURRENT DIRECT.
SATURDAY, MAY 23, 1908. P.M.
TIME.
1:30
1:35
1:40
1:45
1:50
1:55

No. 26.



FERRIC CHLORIDE IN

LONGITUDINAL FIELD.

CURRENT REVERSED.

SATURDAY, MAY 23, 1908. P.M.

Bibliography.

"The Electrodynamic Qualities of Metals".

Sir William Thomson. Math.& Phys. Papers, Vol.II, pp.307-331.

"Alteration of the Electrical Resistance of Copper by Magnetization".

Stewart and Schuster. Phil.Mag.,vol. 164, pp. 535-541, 1874.

"Alteration of Electrical Conductivity Produced by Magnetization".

H. Tomlinson. Phil. Trans., 1883, part 1, p, 133 et seq.

"Ueber den Einfluss der Magnetiserung auf den Leitungswiederstand magnetischer Flüssigkeiten, sowie über eine Methode zur Bestimmung des Leitungswiederstandes von Electrolyten".

F. Neesen. Wied. Ann., vol. 23, pp. 482-490, 1884

"Variations des Proprietes Physiques der Bismuth Place dans un Champ Magnetique".

Hurion Journal de Physique, ser.2, vol.3, p.360, 1884.

"Ueber den Einfluss der Magnetiserung auf die electrische Leitungsfähigkeit der Metalle",

D. Goldhammer. Wied. Ann.,vol. 31, p. 360- , 1887.

"Wiederstandzunahme des Wismuth im Magnetfelde".

Drude and Nernst. Wied. Ann., vol.42, p. 573 et seq.,1891.

"The Electrical Resistance of Cobalt, Iron, and Nickel Films in Magnetic Fields of various Strengths".

J. C. Beattie. Phil.Mag.,vol. 211, pp. 345-353, 1898.

"Sur les Variations de Resistance d'un Conducteur Electrolytique dans un Champ Magnetique".

Bagard. Compt. Rend., vol. 128, pp. 91-93, 1899.

"Change of Resistance of Iron by Magnetization".

Gray and Jones. Proc. Roy. Soc., vol. 67, p. 208, 1900.

"Theory of Electric Conduction through thin Metallic Films".

J. J. Thomson. Proc. Cam. Phil. Soc.,vol.11, p. 120, 1901.

"Indications relatives a la Constitution de la Matiere fournies par les Recherches recentes sur le Passage de l' Electricite a Travers les Gaz".

J. J. Thomson. Rapportes presentes au Congres International de Physique, 1900, vol 3, pp. 138-151.

"Effect of a Magnetic Field on the Resistance of Thin Metallic Films".

J. Patterson. Proc. Cam. Phil. Soc., vol. 11, pp. 118-119.

"Effect of a Transverse Magnetic Field on Metallic Resistance".

J. J. Thomson. Phil. Mag., vol 219, p. 353, 1902.

"The Change of the Electrical Resistance of Metals when placed in a Magnetic Field".

J. Patterson. Phil. Mag., vol. 219, pp. 643-656, 1902.

"The Electrical Properties of Thin Metallic Films".

J. Patterson. Phil.Mag., vol. 220, p. 652 et seq., 1902.

For magnetic effects see page 670.

"The Magnetic Change of Length and Electrical Resistance in Nickel".

W.E.Williams. Phil. Mag., vol.220, pp. 430-435, 1902.

"On the Magnetic Change of Resistance of Iron, Nickel, and Nickel-steel at various Temperatures".

W.E.Williams, Phil. Mag., vol. 225, p.77, 1905.

"Ueber den Einfluss transversaler Magnetisierung auf die elektrische Leitungsfähigkeit der Metalle".

L. Grunmach. Physikalische Zeitschrift, vol. 7, pp.729-740, 1906.

"Effect of Transverse Magnetic Field on Metallic Resistance".

E. P. Adams. Phys. Rev., vol. 24, pp. 428-435, 1907.

"Magnetization and the Resistance of Nickel Wire".

C. G. Knott. Trans. Roy. Soc. Edinburgh, 1907, pp.547-554

"Theory of Metallic Conductivity".

J.J.Thomson. Electrician, vol. 58, pp.839-41, March 1907.
Inst. Elec. Eng. Jour., vol.38, pp 445-465, June 1907.

"Ueber den Einfluss des Magnetfeldes auf den Wiederstand von Elektrolyten".

G. Berndt. Ann. d Physik, vol. 23, pp.932-950, Sept. 1907.

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